Fröhlich's Interpretation of Biology through Theoretical Physics – Liverpool University

Description

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(2nd edition 2008. Chapter 7: pp.107-154) Fröhlich's Interpretation of Biology through Theoretical Physics. Cyril W. Smith (Salford University – Retired)

Abstract

Fröhlich had already considered biological problems in relation to theoretical physics in the 1930's. War intervened and he could not develop these ideas until in 1967, at a conference in Versailles, he considered long-range phase correlations in respect of biological order. He combined the ideas of high frequencies and collective or cooperative behaviour with ideas of long-range phase correlation and coherence and applied them to biological systems. The subsequent development of his ideas and the work of his world-wide circle of collaborators are contained in the two *"Green Books"* which he edited: "Coherent Excitations in Biological Systems" in 1983 and "Biological Coherence and Response to External Stimuli" in 1988.

Subsequent developments from his fundamental ideas are traced out in this Chapter. Work on electromagnetic field and frequency effects has led to the concept of the living system as a macroscopic quantum system with a sensitivity to the magnetic vector potential (A-field). Coherence has been shown to be a fundamental property of water in the ground state and this makes frequency a fractal quantity able to link the chemical, technical and biological frequency bands and a parameter for arithmetic and logic operations. The physics involved also relates to environmental and alternative medicine.

- **Introduction**

Fröhlich belonged to the generation of the founding-fathers of theoretical physics all of whom he knew well. Pauli said of him, *"In Fröhlich we have a physicist who can not only calculate but can think!"* Before and during his tenure of the First Chair of Theoretical Physics at Liverpool University (1948–1973). He made major advances in the theoretical physics of metals, dielectrics, semiconductors, mesons, superconductivity, and the application of theoretical physics to biology.

He had already considered biological problems in relation to theoretical physics in the 1930's. His friend Martin Reiss told him that biological membranes maintain a small electric potential of a tenth of a volt. He asked the thickness and on hearing that it was a millionth of a centimetre realised that this corresponded to the enormous electric field of 10 MV/m which ordinary dielectrics will sustain only when special precautions are taken. The assumption of an elastic constant corresponding to the velocity of sound gave him a likely resonant frequency of the order of 100 GHz. Such frequencies were not available at that time so he sought the help of Willis Jackson to produce them in order to investigate their effects on bio-systems as proposed to him by Victor Rothschild. But, War intervened and he could not develop these ideas until later.

An invitation to a conference on “Theoretical Physics & Biology” at Versailles in 1967 gave him his opportunity. In his paper to this conference (Fröhlich,1969) “Quantum Mechanical Concepts in Biology”, Fröhlich covered: long-range phase correlations in respect of biological order with absorption defining the range of the phase correlations; the excitation of organs to their correct frequency by energy pumping; cell division stimulated by membrane deformations; the cessation of growth when cell concentration suppresses coherent modes of oscillation. He concluded that, “…the application of quantum mechanical processes to complex systems can lead to new points of view provided that quantum mechanics is not used as the servant who tries to derive – with doubtful success – the value of some known parameters but is used as a guide capable of finding regularities hidden in a labyrinth”. In proof, he added that he had been able to show that non-linear interactions will lead to the channelling of supplied energy into coherent modes.

He had learned that a single idea does not produce a theory so he combined high frequencies and collective (cooperative) behaviour with long-range phase correlation (coherence) and applied this to biological systems. This had been found to describe the order found in superconductors, superfluids and lasers. He used to emphasise to us that superconductivity is a consequence of coherence, not of low temperature and that magnetic flux is always quantised.

From general theoretical considerations he concluded that many biomolecules should have metastable excited states with very high dipole moment capable of strongly excited giant dipole frequencies (~100 GHz) and limit cycles, the soliton being a particular case of a metastable state. Work on enzyme activity and the cancer problem followed.

He sought out experimenters producing results of relevance to his ideas. He soon found ongoing work on: Laser-Raman bands in proteins (~ 30 cm^{-1}), coherent EM radiation effects in biological objects (6-7 mm) , *E. Coli* experiments showing a non-thermal Anti-Stokes/Stokes ratio; coherent effects with synchronised cell division, structural properties of cell water and electromagnetic sensing by fish.

By 1967, Fröhlich had already recognised the importance of coherent modes of oscillation in non-linear systems and long-range phase correlations in respect of biological order with absorption defining the range of these phase correlations. He showed that a non-linear interaction will channel energy into coherent modes and that the excitation of organs to their correct frequency could be achieved by energy pumping from metabolic sources. He further showed that within a coherent system, the range of the forces of interaction greatly increased at resonance.

The subsequent development of his ideas and the work of his world-wide circle of collaborators relating to his theoretical predictions are contained in the two *“Green Books”* which he edited: “Coherent Excitations in Biological Systems” (1983) and “Biological Coherence and Response to External Stimuli” (1988).

I was privileged to cooperate with him from 1973 until his death in January 1991. During this period, my students and I provided experimental support for his theoretical work. This included measurements of the large dielectric constants found in moist biological materials; electric, magnetic and RF field effects on enzymes and other biomolecules. The discovery of anomalous diamagnetism led to the possibility of room-temperature superconductive effects. Low-frequency magnetic fields were shown to affect bacterial growth rate and the *lac operon* system. We also investigated, effects under nuclear magnetic resonance (NMR) conditions, magnetic flux quantisation and Josephson behaviour in living cells; the emission of coherent radiation at cell mitosis and environmental EMF effects. From 1982, I became involved in the diagnosis and treatment of electrical hypersensitivity which is still ongoing.

Since his death, my research in these areas has continued. I have worked on electromagnetic field and frequency effects related to environmental medicine, on a multiple-frequencies effect in water and coherent systems which makes frequency a fractal quantity and links the chemical, technical and biological frequency bands. My list further includes, measurements on homoeopathic potencies and serial dilutions; the writing, reading and erasing of frequencies imprinted into water and arithmetic and logic operations on them. The properties of endogenous frequencies found on the acupuncture meridians; the magnetic vector potential (A-field) and Aharanov-Bohm effects also feature. In 1997, I assembled the experimental evidence for regarding living system as a macroscopic quantum system and presented this at the Frontier Sciences Department, Temple University, Philadelphia (Smith, 1998).

I had to develop a dowsing technique for testing patients with extreme electrical hypersensitivity and later used it to investigate the physics behind water's memory for frequency. I demonstrated that dowsing is a quantum phenomenon and that the Aharanov-Bohm effect can be demonstrated in a dowser.

7.2. Quantum Mechanical Concepts and Long-Range Coherence

At the very beginning of his "Quantum Mechanical Concepts in Biology" (Fröhlich, 1969) Fröhlich considered the possibility of quantization on a macroscopic scale giving rise to a new kind of order based on the concept of phase correlations in non-equilibrium systems which are stable but cannot be described in terms of a static or spatial order and further how this might be applied to biological systems.

In this context he wrote (Fröhlich, 1969) :

"Clearly establishment of a useful connection between micro and macro physics requires introduction of relevant macroscopic concepts, and their expression in terms of microscopic(atomic) features. In terms of the latter, macro concepts are always "collective" properties. This programme is well advanced when dealing with behaviour near thermal equilibrium. Relevant concepts are the thermodynamic ones (free energy, entropy, etc.), hydrodynamic fields, properties of special order (crystal structure, etc.), Etc. The study of the peculiar phenomena of superconductivity and superfluidity have revealed, however, existence of a macroscopic special order which is not of such an obvious nature and which is best described in terms of certain quantum mechanical concepts on a macroscopic scale."

He continued by noting that quantum mechanics treats the dynamic behaviour of any system in terms of a state vector or wave function which for a single particle is essentially a de Broglie wave and that a second essential feature of quantum mechanics is that the state vectors of two (or more) states can be superimposed linearly to form a combined state, the probability of which depends on the difference of the phases of its components expressing wave interference which is a characteristic of quantum mechanics.

Fröhlich then discussed how a definite phase correlation could persist over long distances in spite of thermal agitation citing as examples: low temperature phenomena, a single strongly excited longitudinal mode and the laser. He notes that it is not the state function but, a much simpler quantity a macroscopic wave function which persists after thermal averaging and which only depends on space, time and a few other parameters.

He then felt. tempted to postulate the existence of long range quantum mechanical phase correlations in biological systems. This had been suggested to him previously by Per-Olov Löwdin. The strongly polar dielectric character of biological objects suggested the existence of longitudinal oscillations with internal deformations providing additional stabilization but which would be lost at too high cell concentrations. Longitudinal modes are supported within matter but not in free-space so, there would not be any energy loss by radiation. For the sources of the resonances defining these oscillations, he postulated molecular processes involving ions and the biological cell as a structural entity with the possibility that both would interact. He deduced that their resonant frequency would be of the order of 10^{11} Hz (100GHz, 3mm, 3000 µm or $3cm^{-1}$). He assumed that the elastic constants of the cell membrane would give a velocity of sound of the order of 10^3 m/s (10^5 cm/s) in the cell membrane which he regarded as a strongly dipolar layer 10^{-8} m (10nm, 100Å) in thickness.

7.3. Energy Involvement

In 1968, he followed with a paper on “Long-Range Coherence and Energy Storage in Biological Systems” (Fröhlich, 1969a) and “Bose Condensation of Strongly Excited Longitudinal Electric Modes”(Fröhlich, 1968b). In these he showed quite generally that if energy is supplied to such longitudinal modes of oscillation above a certain mean rate, then a steady state will evolve with a strongly excited single mode and that the energy would be stored in a highly ordered way involving long-range quantum mechanical phase correlations resembling the low-temperature condensation of a Bose gas. This fitted in with the general conditions for stability of “dissipative structures” presented by Prigogine at the same Versailles Conference.

7.4. Experimenters Encouraged

Fröhlich proposed a number of experiments he would like to see carried out. He thought it was most important to establish of the existence of coherent vibrations in living systems, a difficult proposition in view of the expected high frequency. In personal communications to him, Palma suggested using Laser-Raman scattering to measure the frequency of the predicted longitudinal oscillations and Careri suggested infra-red investigations.

Following on from this, Fröhlich proposed that experimenters should investigate whether:

1. Excitation would stimulate cell division except for densely packed cells where there should be contact inhibition.
2. Szent-Györgyi had remarked that *cellular activities* like cell division or protein synthesis are largely dominated by the electronic charges of the system. Fröhlich though that increasing the electron density should increase the biological effects until the electron density became so high ($>10^{15}$ cm^{-3}) that the plasma frequency exceeded the resonance mode.
3. Carcinogenic molecules have the ability to transfer electrons to relevant regions of the cell.
4. Screening dipole-dipole interactions between cells with absorbers, filters, or reflectors of known

physical properties would give a measure of the frequency of interaction.

From here on, Fröhlich developed his theoretical ideas in a steady flow of papers. He commented on experiments he considered of relevance. He talked to people. Ferriera suggested to him that his ideas on coherence "… might be of importance for an understanding of the action of enzymes…". This he followed up in a letter to Nature (Fröhlich, 1970) and in his 1974 J.B. Whitehead Memorial Lecture, where he showed how from very general theoretical considerations many biomolecules should have metastable excited states with very high dipole moment capable of strongly excited giant dipole frequencies of the order of 100 GHz.

He emphasised the importance of this for enzyme activity and expanded the idea as a paper on, "The Extraordinary Dielectric Properties of Biological Materials and the Action of Enzymes" (Fröhlich, 1975a) presenting the general theoretical features, noting supportive experimental evidence and proposing further definitive experiments. In another paper that year (Fröhlich, 1974), he noted (quoting Koshland) that, "…while analysis of enzyme structure has led in many cases to the identification of an active site… the essential mystery of their enormous catalytic power remains.".

In 1973, experimenters working on Laser-Raman measurements found strong bands in the 30cm^{-1} region (90GHz) – only a decade below his predicted 10^{11} Hz (Fröhlich, 1973). In January 1973, a USSR Academy of Science meeting received several contributions demonstrating a striking influence of 6-7 mm (50GHz) coherent electromagnetic radiation on a variety of biological objects. Fröhlich referred to this work in his "Evidence for Bose Condensation-like Excitation of Coherent Modes in Biological Systems" (Fröhlich, 1975b), and included details of this and the other work up to 1980 in his survey chapter on "The Biological Effects of Microwaves and Related Questions" (Fröhlich, 1980).

He edited the Journal of Collective Phenomena and in its first issue he discussed "Collective Behaviour of Non-Linearly Coupled Oscillating Fields, with Applications to Biological Systems" (Fröhlich, 1973b). This he said, was undertaken to gain experience in the non-linear coupling of an elastic field with an electric polarisation field which he had commenced in Appendix 1 of his "Quantum Mechanical Concepts in Biology" Fröhlich (1969). He found there were two branches of homogeneous polarisation waves, one which vanished when time-averaged, the other resembling a ferroelectric state. He concluded that the application of a very strong electric field to protein molecules should increase the dielectric constants.

In 1977, he applied this idea to "Dielectric Theory and Ion Channels in Nerve Membranes" (Fröhlich, 1977) and concluded that the nerve membrane potential could affect the conformation of dissolved proteins and possibly ion permeability.

In 1978, he returned to considering "Coherent Electric Vibrations in Biological Systems and the Cancer Problem" (Fröhlich, 1978) presenting experimental evidence for coherent electric oscillations in the 500 – 3000 GHz region especially in biologically active organisms and showing how these might play a decisive role in the control of the growth of tissues and hence in cancer.

7.5. Green Book I

In 1983, Fröhlich directed an International Symposium in Bad Neuenahr (November 29-December 1, 1982). Its papers appeared as his first "*Green Book*", "Coherent Excitations in Biological Systems" (Fröhlich, 1983) in which he surveyed the predictions of his theory of coherent excitations under three headings.

Coherent Excitation of a Single Polar Mode.

Contributions relating to this included evidence that the Laser-Raman effect from cells works down to 200 cm^{-1} where the Anti-Stokes to Stokes ratio must be greater than for thermal equilibrium although the cells must be dilute and synchronised (Drissler & Santo). There were several contributions describing effects produced by non-thermal intensity coherent millimetre wave radiation involving chromosomes (Kremer et al), yeasts (Grundler et al.), *Drosophila melonogaster* (Nimtz) and *E. coli.* (Motzkin et al.). Millimetre and far-infrared spectroscopy showed frequency effects only explicable by dielectric relaxation (Genzel et al). Biophoton emission showed coherence in biological systems at optical frequencies (Li, Popp et al.). Endogenous oscillations of cells were demonstrated by dielectrophoresis measurements (Pohl) and cell rotation (Zimmermann & Arnold).

Excitation of a Highly Polar State.

Contributions relating to this included evidence that the excitation of Langmuir-Blodgett layers of proteins by electric fields produced metastable states (Hasted et al.) and that coherence in membranes was consistent with electron transport phosphorylation in cell energy storage (Kell & Hitchens). There were also descriptions of isotope effects and collective excitations in water (Palma) and self-focussing effects of coherent radiation (Del Giudice et al.).

Complex Effects, Limit Cycles, Lotka-Volterra Oscillations.

Contributions relating to these included: theoretical models for limit cycles (Kaiser), the high sensitivity of biological systems to weak external fields, species specific rouleau formation in erythrocytes (Rowlands), the properties of intracellular water (Clegg), long-range effects in living cells (Welch & Berry) and mechanical forces on particles in an EM field (Sauer).

The two important experimental results which appeared at this stage were firstly, *clear evidence that non-thermal effects were involved in synchronised E. coli in a nutrient medium* where Drissler and Santo measured Anti-Stokes intensities 5-15 times higher in bands assigned to the nutrient molecules assuming that the Stokes intensity represented thermal equilibrium. Secondly, that there were *non-thermal resonant effects on the growth rate of yeast cells following exposure to 42 GHz radiation* with a line width of 8 MHz and satellites at 16 MHz as shown by Grundler et al.

In a review chapter for a book in the series “Advances in Electronics and Electron Physics”, Fröhlich dealt with “The Biological Effects of Microwaves and Related Questions” (Fröhlich, 1980) extending complex effects, limit cycles and Lotka-Volterra oscillations to cover the long-range interactions and non-thermal actions of microwaves in multi-component systems and included in this the cancer problem and brain waves. His section dealing with experiments commenced with an analysis of possible effects of absorbed microwave energy and he insisted that, “…it is imperative to investigate the dependence of a particular biological effect on both frequency and intensity of the microwave.” and furthermore, “It would be wrong, however to conclude that the investigation of fractions of a system e.g., particular molecules, would exhibit a non-linear response to microwaves, for only the whole active biological system shows such properties.”.

Fröhlich noted the effects of microwaves on the brain particularly the EEG and calcium efflux and the differences between the effects of CW and pulsed radiation. In the millimetre wave region, besides the work on yeasts of Grundler et al., he noted effects reported at 70-75 GHz on *E.coli* (Webb & Booth, Berteaud et al.), on the growth and the induction of lambda prophages (Webb), on colicin induction in *E.coli* at 46 GHz (Smolyanskaya and Vilensakaya), on effects on protein metabolism (Manoliov et al.), on effects at 42 GHz on murine bone marrow cells with and without prior X-ray exposure (Smolyanskaya and Vilensakaya). He noted that Laser-Raman work in the 200 cm^{-1} region showed spectra only in cell cultures with added nutrient, not in resting cells. The Laser-Raman spectra of mammary tissues showed differences between “normal” and carcinoma tissues (Webb et al.). Effects were dependent on the time of irradiation with very low intensity radiation, which implied to him that a biological system had the possibility of storing energy until an event for which it had already prepared could be triggered.

During the period between his first and second “*Green Books*”, Fröhlich wrote two survey papers (Fröhlich, 1986a & 1986b) in which he developed his theory of coherent excitations with more work on the action of enzymes. In respect of the considerable bioelectromagnetics research activity at this time, he noted that much of the enormous literature relates to measurements at single frequencies or intensities and this makes any analysis difficult. In “Coherent Excitation in Active Biological Systems” (Fröhlich, 1986a), he updates the experimental results he considers as significant to the year 1986. He noted that Kremer et al. had found the growth of cress roots could be completely stopped 100 seconds after irradiation with 56 GHz at low intensity provided that the radiation was polarised parallel to the root direction.

7.6. Green Book II

Fröhlich’s second “*Green Book*” followed in 1988. It was entitled “Biological Coherence and Response to External Stimuli”. He wrote its introductory chapter which he entitled, “Theoretical Physics and Biology” (Fröhlich,1988) and in it he covered the theory of:

1. **Active biological systems** – stable but far from equilibrium – non-trivial order – extraordinary dielectric properties.

2. **Coherent excitations** – single mode – metastable highly polar ferroelectric state – limit cycles – Davydov solitons as a particular case of a metastable state.

3. **Deterministic Chaos** – something which happens when two very different metastable states occur with equal probability. It leads to lack of experimental reproducibility and effects which only appear in the standard deviations, not in the mean values.

4. **Macro- and Micro- Physics** – the relations between them.

5. **Resonance interactions** between two harmonic oscillations.

    1. **Periodic enzyme reactions** – Lotka-Volterra oscillations in complex systems such as enzyme reactions.

7. **Quantization of magnetic flux** – a completely general property of all materials.

8. **Multicomponent systems and the cancer problem** – cessation of control by excited mode and

transition from order to disorder.

1. **Coherent excitations as interpreters of biological features** – experiments establishing the relevant coherent excitations and the resulting interactions between cells.

Following Fröhlich's introduction, there were thirteen contributions, some theoretical the rest experimental and these are summarised in the following paragraphs.

Fanchon Fröhlich discussed the "Genetic Code as a Language" (which must make use of long-range coherent excitations) covering the restrictions on a genetic language, the interpretation of the genetic code of a single cell having a single chromosome, the linear progression from the nucleotides to the whole chromosome, the requirements of the language and purpose of "junk" DNA.

1. Kaiser in his "Theory of Non-Linear Excitations" gave a mathematical treatment of the occurrence of chaos in non-linear excitations.

Del Giudice et al. presented quantum field theory as a bridge between the macroscopic features of complex systems and the collective properties of microscopic components. Elaborating on the basic proposal of Fröhlich that density of electric polarization was the "order parameter" relevant for biological systems led them to a scheme for living systems with coherence domains of finite size related to a non-vanishing temperature, the confinement of the internal electromagnetic field into filaments, low intensity coherent electromagnetic emission from living matter, magnetic flux quantization and Josephson-like effects, solitons on molecular chains and water electrets.

Grundler et al. in "Resonant Cellular Effects of Low Intensity Microwaves" and Kremer et al. in "The Influence of Low Intensity Millimetre Waves on Biological Systems" provided confirmation of the predictions of Fröhlich's theory in respect of sharply resonant frequencies with a critical rate of energy supply being necessary for effects and the relevance of deterministic chaos to biologically active materials.

Hasted in "Metastable States of Biopolymers" presented direct evidence from dielectric studies for the existence of metastable excited states in Langmuir-Blodget molecular films of protein molecules and bio-molecular electrets.

Drissler in "Physical Aspects of Plant Photosynthesis", used standard methods of optical spectroscopy to analyse excited states involved in the photosynthetic pathway. *Chlorella pyrenoidosa* cells were used and delayed fluorescence emission and Stokes-Raman scattering gave results consistent with the observed Anti-Stokes/Stokes ratio enhancements.

Pollock and Pohl reported on microdielectrophoretic experiments using a wide variety of cell types with the hanging-drop method. High permittivity dielectric particles (<2µm) were attracted to the cells, low permittivity particles were repelled. These effects only occurred with living cells and were maximal near mitosis. The results were consistent with dielectric theory. The maximum effect was in the 4-9 MHz region.

Adey reviewed and reported "Physiological Signalling across Cell Membranes and Cooperative Influences of Extremely Low Frequency Electromagnetic Fields". This involved the way that living systems used electromagnetic fields with low-frequency components. Physical and physiological models were used to interpret effects which included the binding of calcium ions in brain tissue, epidermal and nerve cell growth factor proteins, intracellular enzymes as markers of transmembrane coupling, lymphocyte protein kinase activation, ornithine decarboxylase activity in liver and ovary cell cultures, enzymatic markers for cooperative effects of EM fields and cancer promoters at cell membranes. His models of cooperative organization in physiological systems included, dissipative processes, chaotic models for non-linear oscillating modes, initiation of solitons at cell membranes by electromagnetic field interactions, Lotka-Volterra and cyclotron resonance models of oscillations at cell membranes, local superconductivity activation of enzymes. Cell membranes were identified as the primary site of interaction with calcium ions and these played a key role in stimulus amplification.

Rowlands investigated “The Interaction of Living Red Blood Cells” which show attractive forces (even though negatively charged) leading to rouleau formation. Using the techniques of hæmacytometry and quasi-elastic light scattering to detect deviations from Brownian motion he obtained results in agreement with theory.

Fröhlich asked me to cover “Electromagnetic Effects in Humans”. I introduced this with a survey of our work on the effects of coherent electromagnetic fields on enzymes and cells and led in to my work on electromagnetic hypersensitivities in highly allergic subjects and included a description of diagnosis techniques and therapies available. The latter were based on Miller’s technique involving the use of serial dilutions of allergens. One attempted to find a dilution which would neutralise the EM effects on the patient. This led me to study the effects of coherent frequencies imprinted into water. These are covered in Section 7.8.

Kell gave a broad overview of “Coherent Properties of Energy-Coupling Membrane Systems” in respect of ATP linked to the transport of electrons down their electrochemical potential gradient catalysed by biomembranes containing mobile protein enzyme complexes.

Hameroff dealt with “Coherence in the Cytoskeleton: Implications for Biological Information Processing”. He discussed coherence models for the cytoskeleton regarding it as a dynamic information-processing system capable of organizing cell movement, division, growth and behaviour.

This survey of Fröhlich’s second “*Green Book*” reflects the state of theory and experiment up to about 1986. In its Preface, Fröhlich wrote:

“The existence of coherent excitations in active biological systems has been established in recent years. The present book aims at presenting a survey on the many features that such excitations can exhibit. This does not mean that a “theory of biology” has been established but it implies that such a theory will make use of such excitations. It is hoped that the present book will help in this direction”.

After his two “*Green Books*”, Fröhlich wrote just two further papers on biological topics. He told me that he had been asked to look again at some of his early work on mesons. For a meeting of the Institut de a Vie in 1988, he wrote on the “Stabilisation of Non-Linear Excitation in Biological Systems” In 1990, for a meeting on “Consciousness within Science” in San Fransisco he wrote on “The Connection of Macro and Micro Physics” but he could not present it owing to illness due to the effects of jet-travel.

7.7. Fröhlich at Salford University

According to my diary, my first meeting with Professor Fröhlich was in Professor Calderwood's office at Salford University on the 11th. June 1973. In 1968, Fröhlich had proposed that the polarisation of electric dipoles was the 'order parameter' relevant to biological systems thus, their dieletric properties should demonstrate this long-range order. Professor Calderwood had built up a considerable dielectrics research activity in the Electrical Engineering Department and Salford University was less than 30 miles from Liverpool University.

At that time, I and my students were working on high electric field phenomena in liquid dielectrics although, I also had some ongoing bio-medical projects.

This Chapter represents the first occasion on which I have had an opportunity to summarise in its entirety the work done with Fröhlich's active encouragement and cooperation and its continuation after his death.

Following further meetings with Fröhlich in October 1973, my laboratory notebook records that my dielectric measurements on biological materials commenced on the 18th. Decemeber 1973. By then, a special measurement cell had been constructed for me to use with materials such as powders of biomolecules. These were used as obtained from laboratory suppliers. My measurement technique was based on that for measurements on liquids. A weighed quantity of the powder was placed in the cell and its capacitance obtained by extrapolation of the linear plot of applicator separation against the reciprocal of the cell capacitance.

The first materials I investigated were ribonuclease and ribonucleic acid. I then found that samples could be measured immersed in n-hexane to prevent changes of humidity. This also prevented breakdown over the surface of the damp enzyme particles and enabled capacitance measurements to be made with applied steady electric fields up to several hundred kV/m.

Fröhlich kept in touch with this work by visiting Salford every month or two and by correspondence. In March 1973, he brought me some triclinic crystals of lysozyme grown in Oxford for the investigation of the structure of lysozyme by X-ray crystallography. I measured their dielectric properties using metal applicators evaporated on to microscope slides. Fröhlich arranged for me to visit Professor DC Philips and Dr. MW Makinen in the Laboratory of Molecular Biophysics, Oxford University, to see to see their lysozyme crystal growing and handling techniques[1].

Following Fröhlich's suggestion, I started to measure the effects of temperature and humidity on commercially available lysozyme. My own efforts were soon supplemented by those of a research student (Ahmed, 1976a). We found a large increase in the dielectric constant and loss as its humidity was increased by absorption of water vapour, this reversed on desiccation by storage over silica gel. Temperature cycling the dry lysozyme gave a closed hysteresis loop for both dielectric constant and loss. For humid lysozyme measured at 2kHz, both increased to several hundred up to about 39?C. Then, there was a sudden decrease which persisted during cooling. Exposure to an electric field just below the 39?C transition temperature prevented this decrease. Tetragonal lysozyme crystals and other enzymes also showed permanent changes following the application of an electric field.

In January 1975, Fröhlich wrote asking whether I could measure any electric field induced hysteresis in single lysozyme crystals at high temperatures where he envisaged the required field magnitude would be less, he concluded, "If the hysteresis is connected with conformational change then it might be observable by X-ray measurements.”.

The magnetic field from a permanent magnet (0.14T) applied perpendicular to the measurement capacitor gave a reduction in the dielectric constant and loss of about 40% for humid lysozyme, ribonuclease and ovalbumin. These preliminary results were presented (Ahmed et al., 1975) at a dielectrics conference in July 1975[2].

Fröhlich realised that large magnetic field effects implied an anisotropy in the dielectric constant and that the crucial test was to determine the magnetic susceptibility. A few preliminary experiments on lysozyme solutions using the Quincke method established that diamagnetic susceptibility was involved. Fröhlich immediately pointed out that diamagnetism can only arise from the equivalent of a short-circuited current loop.

We followed this by measurements using the Curie method with a torsion balance improvised from a mirror galvanometer discovered in a teaching laboratory with a burned-out coil but intact suspension. A 1½” electromagnet was available; this could only be calibrated for magnetic field (not the gradient) so no absolute susceptibility measurements could be made. Calibration was done using water, sodium chloride and manganese sulphate (all ANALAR grade). The lysozyme solutions were contained in borosilicate glass bulbs weighing 50-100 mg freshly blown from tubing.

In these susceptibility measurements we investigated the effects of temperature and temperature cycling with dry and crystalline lysozyme and lysozyme solutions of various concentrations, pH effects and whether dielectric measurements compared with enzyme activity. The susceptibility effects were maximal for 0.01% concentrations of lysozyme at 60 mT (600 gauss[3]) 23?C and pH 5 but, also at the isoelectric point pH10. After all our experiments we found that deposits of lysozyme remained on the inside walls of the glass bulbs. These resisted cleaning and were further investigated since they showed anomalous diamagnetic susceptibility effects in their own right.

A report of this work was submitted to Physics Letters (Ahmed et al., 1975) on the 12th. April 1975 and published in the 2nd. June 1975 issue. Fröhlich wrote the discussion and generously put my name in the place of honour. He pointed out that although the dielectric constant is very sensitive to the diplacement of single ions, magnetic field effects must be able to overcome thermal fluctuations and that in this case a volume containing of the order of 10^6 lysozyme molecules must be involved, this would be about 0.5 µm in size and of bacteria dimensions. The existence of a critical field above which the effect disappears implied the occurance of the Meissner Effect as in superconductivity and that there must be small superconductive regions of dimensions less than the London penetration depth associated with lysozyme. This was our first evidence that we were dealing with domains of coherence. It is fundamental to any coherent magnetic field effect that a certain volume of field is required to have enough magnetic energy to overcome thermal disordering. We assumed that this was solely associated with the lysozyme molecules although with hindsight, there were small but consistent magnetic field variations in the magnetisation and susceptibility of our pure water if the measurements on the quartz cells are taken as an index of the experimental accuracy being achieved. At this time, there was no theoretical reason to expect coherence domains as a fundamental property of water. This came with the quantum electrodynamics theory of Preparata and Del Giudice twenty years later.

Fröhlich pointed out that superconductivity could give rise to an AC Josephson Effect resonating with the electric vibrations in biomolecules he had postulated in 1968. He had predicted 10^{11} Hz and at the

Josephson interconversion (2e/h) of approximately 500 MHz/µV the AC Josephson voltages would have been 200 µV. He frequently emphasised to us that superconductivity was the consequence of coherence not of low temperatures, and any system which could achieve the necessary coherence would acquire these properties. The involvement of the magnetic vector potential is implicit in the wave equations. Fröhlich did not specifically discuss the possibility of living systems being sensitive to the magnetic vector potential (**A**-field). This is crucial for assessing the effects of environmental electromagnetic fields on living systems since, if living systems can react to it, absorbed dose rates (SAR) and temperature rises become nonsensical as EMF exposure safety criteria[4].

Following the measurements with our improvised apparatus, Dr. Booth in our Physics Department allowed us to use his apparatus which could measure magnetic susceptibility more precisely. This comprised an electromagnet with shaped pole pieces to give a uniform gradient of magnetic field and a Cahn-RG microbalance for which the limit of detection was 10^{-7} gm wt. Since this was a null-balance instrument, the sample remained in the same position in the magnetic field gradient throughout. The field and gradient were calibrated using a standard bismuth specimen. Repeatability depended on care in sample preparation and the exclusion of any paramagnetic or ferromagnetic contamination. The lysozyme solutions were made up in highly de-ionised water in polythene without use of metal tools, no magnetic stirrer, nor shaking to produce froth which is a sign that the enzyme has de-natured. All measurements were made in ambient air. The containers were freshly made from quartz and were flame sealed after filling to prevent measurement drift due to evaporation. It was found that once the quartz had been in contact with lysozyme solution, the empty container gave a very large reading which could not be removed by repeated washing with water or detergents. Baking in air to 200?C for an hour did restore the cell to its original state but in this work as before a new container was made for each experiment. Sterilising the lysozyme with UV or autoclaving did remove the magnetic effects but probably because the lysozyme had been denatured. Measurements on lysozyme, dry, humid and in solution were made over a range of temperatures, temperature cycling and magnetic fields. The results agreed with those previously measured.

In the course of later work, we found that the water from the de-ionizer contained live biological cells. While these might have stimulated the lysozyme to anomalous activity, they would not have been present in the ANALAR water nor the water vapour experiments which also showed these effects.

We considered the possibility that our susceptibility changes were not due to increased diamagnetism but to paramagnetic oxygen being expelled from the lysozyme solutions at certain fields and temperatures. To check this hypothesis, the de-ionised water was compared to an aliquot which had nitrogen gas bubbled through it for 3 weeks; there was no significant difference. Further control experiments were made. Deuterium oxide showed only a little susceptibility variation with either magnetic field or temperature. No magnetic field variations of susceptibility were found for polynucleotide materials (the constituents of DNA). The chemical reaction rate of lysozyme is inhibited by n-acetyl-d-glucosamine, adding this to a lysozyme solution greatly reduced its susceptibility variations with magnetic field. An account of these susceptibility measurements was subsequently published (Ahmed, 1976a, Ahmed et al., 1976, Ahmed and Smith, 1978).

The tunnelling of single-electrons and Cooper-pairs through thin films gives a measure of the energy gaps involved and should be sensitive to magnetic fields. Thin sandwich layers comprising films of : *aluminium – aluminium oxide – lysozyme – lead* were found to give voltage-steps which were changed by exposure to the corresponding AC Josephson frequency and which disappeared at 80 µT (800 gauss) which was the critical strength of magnetic field that removed the diamagnetic susceptibility anomalies. From this we concluded that an enzyme system at ambient temperature could have the same degree of coherence as occurred in low-temperature superconductivity.

One of my students was working on the energy analysis of field emitted electrons which had tunnelled through thin layers of organic molecules on the tungsten tip and we included lysozyme in his programme. The total energy distributions (TED) showed a considerable amount of structure which was interpreted in terms of elastic resonance tunnelling and inelastic tunnelling for either electron-phonon or electron-electron interactions. The results in general agreed with those obtained by tunnelling through thin sandwich layers between applicators and with the infra-red spectra of the materials. The TED structure for lysozyme showed peaks above the Fermi level similar to those observed from anthracene (Kagiafas, 1977).

In the mid-1970's, Fröhlich became particularly interested in long range coherence and the action of enzymes and I was fortunate in having a student with a biochemistry background who was able to investigate the effects of magnetic and radio frequency fields on the activity of lysozyme (Shaya, 1983). We used the live substrate *Micrococcus lysodeikticus* rather than a synthetic substrate so as to be able to investigate an active biological system which was of particular interest to Fröhlich. Lysozyme disrupts the bonds between polysaccharide molecules in the cell walls to produce dimers with a consequent reduction in turbidity as measured with a spectrophotometer. The effects of magnetic fields on the lysozyme activity were between 10% and 50% with both increases and decreases being observed. There was evidence of magnetic field memory, effects were observed whether the magnetic field was applied during the reaction or even a few hours beforehand. No magnetic stirrer was used throughout these experiments. The effects of magnetic fields were increased to 100% if the competitive inhibitor n-acetyl-d-glucosamine was added to give a 10% reduction in the lysozyme activity. Radio frequency fields from 50 kHz to 300 MHz gave effects with maxima and minima which were frequency dependent but did not increase the activity beyond its uninhibited value. There was a concentration dependent delay time for the reaction which Fröhlich regarded as characteristic for the establishment of coherence in a system. The effects of pH, temperature and substrate incubation time were investigated.

Eventually, I acquired within my electrical laboratory facilities for doing cell biology and had a student (Aarholt, 1982) able to investigate the effects of weak magnetic fields on the anaerobic growth of the bacterium *Escherichia coli* (NCTC 9001). This was selected because of its short generation time, ease of cultivation, no tendency to cluster and the considerable literature.

Steady magnetic fields gave a 2% reduction in the mean generation time (MGT) below 100 mT (1000 gauss) and an increase up to a few percent above 160 mT (1600 gauss) with some inhibition at 450 mT (4500 gauss).

Alternating magnetic fields with sine-, sawtooth- and square- waveforms at 50 Hz and 16.66 Hz were investigated. For these measurements, a special electromagnet with long limbs was constructed along which a stack of 18 culture cuvettes could be exposed simultaneously so that no field strength went untested. Controls were cultured inside a mu-metal box giving effectively zero field conditions. More than 1000 test cultures were measured and the F-ratio test indicated a probability of less that one in two million that these magnetic field effects on the MGT were due to chance. There was a distinct threshold of magnetic field for the onset of any effect on the mean generation time. This was at about

480 µT (4.8 gauss) peak and corresponds to a single quantum of magnetic flux linking the measured cross section of a cell. A periodicity in the effects of higher magnetic fields is consistent with odd numbers of magnetic flux quanta linkages reducing the MGT and even numbers increasing it. The overall standard deviations of the cultures were 0.8% in the ambient geomagnetic field, 1.2% in zero field and 1.7% in 50Hz fields.

The rate of indole production in *E. coli* mirrors the mean generation time and its variations with magnetic field were measured. These showed the same magnetic field effects although it was a less sensitive test.

The ?-galactosidase synthesis by *E. coli* was found to be a more sensitive test of magnetic field effects. The transcription of the ?-galactosidase gene is controlled by a repressor protein which binds very strongly to a specific site on the DNA located just outside the structural gene. Magnetic field strengths between zero and 0.7 mT (7 gauss) were used as our previous work had shown particular sensitivity in this region. A square waveform magnetic field was used so as to be able to specify the field strengths precisely. There was a very sharply defined decrease in the ?-galactosidase synthesis to about one-fifth at 0.3 mT (3 gauss) and a less sharp (or double peaked) increase to more than twice the control value at 0.54 mT (5.4 gauss). The effect was maximum for cell concentrations between 3.6×10^{7} and 5.0×10^{7} cells/ml, representing about 30 µm mean cell separation and vanished when the inter-cellular separation was less than 20 µm suggesting that long-range order was involved as predicted by Fröhlich. It seems clear that a magnetic field can have effects at the DNA/RNA level. If our measurement points had been taken only at gauss intervals, these effects would have been missed completely. This shows the precision with which Nature uses field effects for its own purposes.

When *E. coli* was cultured under proton nuclear magnetic resonance conditions (NMR), there was a 3.5% decrease in the MGT relative to the controls with 50 Hz magnetic fields; there were smaller effects at 10 Hz, 16.66 Hz and 100 Hz.

The results for the growth of a soil bacteria (strain BDF80) under proton-NMR conditions were even more spectacular. While optical absorption data showed the same concentration of cells in both exposed and control cultures, optical microscopy showed that the exposed cultures contained twice as many cells half the size of the controls although, the total cell mass of both cultures was equal. This implies that exposure to proton NMR conditions accelerates DNA replication so that the exposed cells are ready to divide at an earlier stage in the cell cycle than the controls.

There was a Conference on “Organic and Biological Semiconductors” in Nottingham in 1980 on the occasion of the retirement of Professor D.D. Eley, at which Professor Herbert Pohl presented some ‘unsmoothed’ results of dielectrophoresis experiments on living cells. These showed sharply resonant anomalies in the region of 2 kHz which happens to represent proton nuclear magnetic resonance (NMR) in the geomagnetic field. The NMR conditions make frequency proportional to magnetic field. This was evidence that living systems could sense the small energies involved in the geomagnetic field[5]. In NMR technology, a strong magnetic field is used to get a high frequency with enough energy to be measured.

Each student in my laboratory was allocated a different cell type so that we should know from whom any cells had strayed. This never actually happened, thanks to the course on cell techniques provided by our Biology Department which they had attended.

The students who followed up this observation (Jaberansari, 1985; Jafary-Asl, 1988) were allocated yeast cells (*Saccharomyces cereviciae* – normal diploid) for the dielectrophoresis and subsequent experiments. These cells are large (5 µm), easy to grow, have a simple shape, are non-motile, multiply by budding and have a thick (8 nm) cell membrane which will withstand the de-ionised water necessary to get a high electric field for dielectrophoresis at a point applicator. The anomaly at NMR conditions was reproduced in live cells but not found in cells killed by exposure over-night to 254 nm UV light or by autoclaving at 121?C. Dielectrophoresis is a dielectric phenomenon, the corresponding anomaly was sought and found in dielectric measurements of cell suspensions. The resonances were very sharp, about 1 Hz in bandwidth. They were also found at the NMR conditions for the magnetic isotopes ^{39}K, ^{35}Cl, ^{23}Na, ^{31}P, in a proton conductive glass (pH meter probe) and also at the electron spin resonance (ESR) condition.

Remembering the voltage steps previously obtained (Ahmed, 1976a) in the voltage-current characteristics of thin films of lysozyme, this work was repeated with dielectrophoretic pearl-chains and single yeast cells (Jafary-Asl, 1983). After running 1000 aliquots at intervals of 5 minutes, voltage steps were detected but only for 2-3 minutes around the time of cytokinesis in the cell cycle. For a single yeast cell, the step voltage distribution had a maximum at 474nV corresponding to an AC Josephson frequency of 237 MHz although the voltage steps ranged from 158 nV to 1264 nV. Once the experimental conditions for voltage steps had been found, it became worthwhile to look for the corresponding frequency emissions. Eventually, these were detected one mean generation time (MGT) after incubating the cells for synchronous growth and in darkness. Starting cells dividing synchronously involves giving them an ionic shock which gives the cell membrane that deformation which Fröhlich predicted would be necessary. All this took about 4 hours at the temperature of the screened room used for these measurements. When they occurred, the coherent emissions were at 7-8 MHz and 50-80 MHz and of amplitude a little greater than the noise level of the spectrum analyzer. They only lasted for a minute or two. They first appeared with a bandwidth of about a MHz but this quickly decreased. The minimum bandwidth measured was about 50 Hz in 7 MHz. This is consistent with the quantum noise of 7 MHz photons. Professor Sydney Webb pointed out to us that this frequency corresponds to the rate of ATP hydrolysis which would be needed to supply the energy for cell division so we may have had an example of a coherent chemical reaction. Other effects around 8 MHz were noted by Fröhlich and appear in his second “Green Book”.

Further measurements were made under NMR conditions and are included in an invited chapter on “NMR Conditions and Biological Systems” (Aarholt et al., 1988). The use of evaporated metal applicators enabled us to make dielectrophoretic measurements on pearl chains and single cells using a high power optical microscope. When proton NMR conditions were satisfied, some cells in the pearl chains developed a force of repulsion implying a drastic change in their dielectric properties (Jaberansari, 1985, 1989).

A student with a biological background investigated “The Biological and Biochemical Effects of Microwave and Radiofrequency radiation on the Bovine eye Lens *in vitro*”. (Marsh, 1986). When proton NMR conditions were satisfied, extensive subcapsular and posterior cataracts were produced by radiation at 2GHz with 3.35 kHz modulation under the following critical conditions: incident microwave intensity 1-2 µW/cm^2, frequency of magnetic field sweep through NMR condition 0.01- 0.07 Hz. The exposure time of 18 hours was followed by 24 hours incubation before examination.

Fröhlich had proposed that biological systems might possess a metastable state with a high electric dipole moment. To investigate this we exposed cells in suspension in a highly de-ionised but osmotically compatible solution to a rotating electric field. They responded by rotating at speeds in the range 0.1Hz – 10 Hz to frequencies in the range 1-100 kHz. The speed depended on the phase of the cell cycle. The speed of rotation was measured by strobe illumination through the microscope mirror. The rotation was not observed for dead cells. The cells examined were *Saccharomyces cerevisiae* and in cooperation with the Biology Department *Leishmania major.* We found that the latter could be cultured *in vitro* if the surface of the petri dish was given a static negative charge by electron bombardment.

In 1982, Aarholt and I wrote a letter to the Journal "Health Physics" pointing out that chronic exposure to environmental electric fields should stimulate the production of those endogenous opiates which are deliberately stimulated for dental anaesthesia and hence the environmental effects would not become apparent until withdrawal from the field when field measurements then would be useless (Smith & Aarholt, 1982). This fitted in with contemporary environmental thought and I received a letter from Dr. Jean Monro[6] asking whether I could help with her electrically sensitive patients. It soon became clear that what mattered was the presence of some highly coherent frequency to which the patient had acquired a sensitivity. Once some threshold intensity had been exceeded, intensity was of little further significance. My involvement in this work continues. In January 1986, Fröhlich asked me to include it in my chapter for his second "*Green Book*" (Frohlich, 1988) which I entitled "Electromagnetic Effects in Humans".

This was the time of university cut-backs. I was offered and accepted early retirement as from the academic year 1989-1990 and although I held a part-time teaching position for a further three years, I could no longer supervise research students. I still had one student working on "An Investigation of Memory Phenomena in Water", this he wrote up as an MSc thesis (Tsouris, 1991). I was unable to find him a supervisor at Salford University but did I find someone at the University of Surrey where he completed the work for his PhD (Tsouris, 1995) during which time I paid regular visits. This work showed that although it was possible to make objective measurements on frequency imprints in water. The signals appeared as large changes in the mean and standard deviations consistent with a Poisson Distribution. The signals were very coherent requiring a long wait for a resonance to build up so statistical analysis was used.

I continued to make regular trips to Liverpool University to visit Fröhlich until his death on the 23rd. of January 1991 when I had just returned from deputising for him at a conference in Tucson AZ. He died before I could get to visit him in hospital.

7.8. Post-Fröhlich

7.8.1 Continuation

Retirement left me free to continue those lines of research which interested me but, without the facilities of a university. I shall confine this section to those aspects of my work in this period which stemmed from Fröhlich's Interpretation of Biology through Theoretical Physics. In his 1967 paper "Quantum Mechanical Concepts in Biology" (Fröhlich, 1969) Fröhlich introduced quantum physics into biology. It was not until 1997 that my own work had progressed to the stage where I could summarise the experimental evidence for this in a talk I gave to the Frontier Sciences Department of Temple

University, Philadelphia which I entitled "Is a living system a macroscopic quantum system?" (Smith, 1998). Fröhlich once said to me that I knew enough about coherence in biological systems but it might take me two years or twenty years to understand it, I am past the twenty year mark.

7.8.2 Measurement Problems

The objective measurement of coherent frequencies in water and living systems was and still is the main obstacle to progress. One is seeking to get sufficient coherence in a water or a biological system for its macroscopic wave function to generate a classical electromagnetic field, the highly coherent frequency of which is what can be detected and processed by instrumentation. At present, the only practical method for detecting resonances over the clinically significant range from milliHertz to GigaHertz is to use human sensitivity such as through the dowsing response or a muscle reaction as used in kinesiology[7].

I have been measuring frequencies by dowsing for the past twenty years[8]. The technique was developed out of necessity. I needed a way of determining the frequencies to which electrically hypersensitive patients were reacting, these were patients so sensitive as to be incompatible with modern technology. They could not tolerate an electrical oscillator at one of their sensitive frequencies turned on anywhere in the building. The less sensitive patients could be tested with an oscillator at field strengths typical of the modern electrical environment. Eventually, I found that patients could imprint their whole-body frequency information into water if they held a robust glass tube of water in the fist and banged the glass end on a wooden surface (in homoeopathic terms *succussion*). I then measured the imprinted frequencies by dowsing the tube far away from the patient. I still use this technique for clinical work as an imprinted tube can be wrapped in aluminium foil and sent through the mail for me to measure and interpret.

A water frequency imprint (order) propagates down a wire or through water by diffusion just as heat passed along the handle of a saucepan (disorder). Its velocity can be measured by interrupting its path with a relay or a transistor or by measuring its critical angle for total reflection at an interface. In water its is about 2.6 m/s, in the human leg it is about 6 m/s. A soliton is described by a non-linear diffusion equation so this would be the experimental situation in which to seek evidence for solitons.

If coherence in water is arranged to propagate past both sides of a solenoid as in the basic arrangement for the Aharanov and Bohm experiment, there is a phase alternation in the dowsing reaction proportional to the current in the solenoid (Smith, 1995, 2004). This suggests that the dowsing reaction involves the unbalance of the left and right body fields by whatever is being dowsed. Since millihertz frequencies can be measured within a second, this implies a phase comparison is made between two highly coherent oscillations.

The heart and pericardium acupuncture meridians run up the arms to the axilla. If the acupuncture points He9 or Pe9 on each hand are joined together (resistance < 5 MW), all dowsing response is lost. This does not happen for any other acupuncture points on the hands or feet. It suggests that a dowser's sensing mechanism involves sensing a phase unbalance between the left and right side endogenous frequencies on the heart and/or pericardium acupuncture meridians (Smith, 2000). Each dowsed phase reversal represents a phase shift of p between the wave functions for the left and right sides of the body; where they overlap the macroscopic wave function is the superposition of the contributions from both sides of the body and this is where the water to be measured is placed.

My view of the origin of the acupuncture meridians is that coherence is set up between the ectoderm and the endoderm in the presomite stage of the embryo and this persists as the organism develops giving at maturity a channel of communication between the acupuncture points and the target organs (Smith, 1990).

My continued involvement with clinicians treating allergies and electrically hypersensitive patients with serial dilutions of an allergen led me to investigate the physics of water. Frequency was the parameter which mattered to these patients once some threshold of intensity had been exceeded. I looked into the relevance of coherent frequencies in living systems as a scientific basis for the various therapies used in 'Alternative Medicine' particularly homoeopathy and acupuncture.

'Classical' & Voll Acupuncture Meridians	**Point Measured**	**Low Band Frequency**	**High Band Frequency**
		Hz	**MHz**
Nerve Degeneration	ND1	0.00055	0.027
Kidney	Ki1	0.00095	0.047
Skin Degeneration	Sk1	0.0035	0.172
Small Intestine	SI1	0.025	1.2
Stomach	St45 / right	0.044	22
Circulation, pericardium	Ci9	0.05	2.46
Gall Bladder	GB44	0.05	2.46
Large Intestine	LI1	0.055	2.7
Spleen	Pn1	0.055	2.7
Lymphatics	Ly1	0.06	2.95
Organ Degeneration	Or1	0.078	3.85
Pericardium	Pe9	0.25	13
Joint Degeneration	JD1	0.3	148
Stomach	St45 / left	0.44	2.2
Lung	Lu1	0.48	24
Fatty Degeneration	FatD1	0.74	36
Allergy	AD1	2.0	98.4
Du Mai (GV)	GV14	4.3	149
Liver	Liv1	4.8	240
Urinary Bladder	BL67	5.5	270
Heart	He9	7.8	380
Ren Mai (CV)	Ren24	14	730
Fibroid Degeneration	FibD 1	800	39,400
Anmian I & II	Ex 8 & 9	3,000	
Sanjiao (TW)	TW1	6,000	300,000

Table 7.8.1

Nominal Values for Endogenous Frequencies on Acupuncture Points

I found a whole range of endogenous frequencies were present on the chakras, acupuncture meridians, and additional frequencies at the points of connection with the autonomic nervous system (ANS) as listed by Dr. R. Voll (Smith 2005a). The frequency characteristic of the sympathetic ANS is $\sim 3\times 10^{-3}$ Hz and that of the parasympathetic ANS $\sim 3\times 10^{-1}$ Hz. The nominal values for the acupuncture meridian frequencies are listed in Table 7.8.1.

I presented aspects of this work as it developed at the International Annual Symposia on “Man and His Environment in Health and Disease” held in Dallas, Texas, between 1986 and 1994 and at the 1997, 2000 and 2005 Symposia (Smith, 2000, 2005a).

7.8.3 The Cancer Problem

In 1978, Fröhlich returned to the cancer problem (Fröhlich, 1978) presenting the accumulated experimental evidence for coherent electric oscillations in the 500 – 3000 GHz region especially in biologically active organisms. He showed how these frequencies might play a decisive role in the control of the growth of tissues and cancer in particular. Endogenous frequencies seem to be generally present in living systems from simple cells to humans and extend from milliHertz to GigaHertz. In Dallas, we demonstrated that exogenous frequencies can entrain, synchronise, re-programme a living system thereby introducing erroneous bio-information which persists into their daughter cells (Smith,2000).

In the cancer context, our 50 Hz power supply frequently blamed for leukaemia clusters. Archived microscope slides of blood contain enough residual water even after slide preparation and storage for their characteristic frequencies to be retained and to be measurable. Frequency measurements of a slide prepared from a myeloid leukaemia blood showed the presence of 50 Hz which was not present in the ‘normal blood’ slide. Homoeopathic sulphur in low potencies might be considered for leukaemia therapy. It contains frequencies closely matching those in the myeloid leukaemia slide but in the opposite phase of biological activity (i.e. hyper- versus hypo-). When the myeloid leukaemia slide was measured in contact with a vial of sulphur 30C, the result was a phase cancellation leaving the single frequency (7.992 Hz) of the heart meridian in the stimulatory phase which is generally therapeutic.

At the Environmental Health Center, Dallas, Texas, one of the research programs (Griffiths, 1998) was concerned with the development of a laboratory technique to correlate the clinical diagnoses of organo-chemical toxication in patients with the progress and outcome of the treatment programs for environmentally induced illnesses. In this work, the pattern of occupancy of the various phases of the normal cell cycle for peripheral T-lymphocytes was determined through flow-cytometry measurements. The effect of all common organo-chemicals (or frequency imprints) was to interrupt the ordered and orderly progression of the cell cycle by entrainment of cell frequencies from their normal fluctuation and synchronise them to coherent electrical frequencies or chemical frequency signatures. This resulted in the destruction of specific proteins and enzymes preventing apoptosis from taking place with the result that wrong translations are made from the DNA and wrong signals are sent for the control of cell progression thereby compromising the immune system and leading to multiple manifestationsincluding cancer.

One important question is, *What can frequencies do?* and one answer is that they can change isomeric structure. Fröhlich realised this possibility in respect of nerve membrane potentials (Fröhlich, 1977). Amino acid isomerisation is changed from L- to D- following exposure in a microwave cooker (2.45 GHz) (Lubec et al. 1989). There is another frequency which will effect the D- to L- transformation. Enzymes are built up from amino acids and are very sensitive to their tertiary structure.

7.8.4 Coherence in Water

One theoretical concept that Fröhlich did not reach was hinted at in the second "*Green Book*". In the chapter by Del Giudice et al., filaments of coherence are discussed. In 1995, Del Giudice with Preparata showed through quantum electrodynamics (QED) theory that water had coherence as a fundamental property in its ground state arising from the exchange of radiation at the natural photoabsorption resonances of the water molecule (Arani et al., 1995). This coherence was confined to domains of size determined by the coherence length which was twice the wavelength of the spectral line involved. The 12.06 eV spectral line, close to the ionisation potential in the far ultra-violet, had the highest probability of being the first to form a coherence domain when water vapour condensed to the liquid phase. They were able to show that a permanent coherence can become established and give rise to a long-range-order within domains 75 nm in size. This coherence is in the ground (unexcited) energy state of water. It is a fundamental property of liquid water; unlike the laser no energy pumping is required to establish this coherence. Fröhlich's model needs a supply of metabolic energy and this is applicable to active biological systems as he so describes but, there is another level of coherence which relates to bio-information in water and clinical applications such as homoeopathy.

Within a coherent system, external radiation will interact with the entire coherence domain or, not at all. The scattering of radiation by individual molecules gives matter its refractive index. In a coherent system the coherence length is constant and the velocity becomes proportional to the frequency. This consequence of coherence in water forced itself on my awareness many times. If the coherence length becomes the constant parameter then frequency is proportional to the velocity with which the coherence propagates. This makes frequency a *fractal* quantity with no absolute scale. Any velocity that the system can support will have a corresponding proportionate frequency and each can and will interact. It is this which links chemical spectra to technological and biological frequencies. It also allows coherence to propagate with superluminal velocity within a coherence domain if the frequency is high enough, energy is only involved in setting up the coherence domains initially. This can be detected between living systems by measuring the critical angle for total internal reflection, which appears on the air side of an air/water interface.

In one experiment, water was imprinted with frequencies ±0.6 GHz relative to 1.42 GHz (molecular hydrogen resonance). This was chosen to keep within the range of a single oscillator. There is no coherence interaction and no refraction at 1.42GHz. At 0.8 GHz (1.4-0.6 GHz) the 45º critical angle for total internal reflection was within the water (coherence velocity 210 Mm/s). However, at 2.0 GHz (1.4+0.6 GHz) the 45º critical angle was on the air side of the interface (coherence velocity 420 Mm/s). This represents an anticipatory channel of communication but, it is coherence which is propagating not energy. If living systems can utilise this superluminal information channel, then they should have a "Maxwell's Demon" available.

Using QED theory (Arani et al., 1995) showed that water at 300 K was a mixture comprising 28% coherent water in 75 nm domains interspersed with the remaining 72% as incoherent or vapour-like water. It is the coherent water that has the "memory" properties. The incoherent water is responsible for the normal thermodynamic properties. This theory was the first to give the experimentally determined values for many of the physical properties of water including: critical volume; boiling temperature; latent heat of vaporisation; specific heat; the specific heat and compressibility anomaly at 230K; density anomaly at freezing point and the low frequency dielectric constant for water. Fröhlich applied the Kirkwood formula to get a value of 63 for the static dielectric constant of water compared with the experimental value of 78 (Fröhlich, 1949).

The "Classical" Electromagnetic Field describes physical states for which the phase is well defined but the number of particles (quanta) is undefined. For a Quantum Field the uncertainty of the phase (DF) and the number of particles (DN) is determined by the Heisenberg Uncertainty Relation

(DF) (DN) $\geq$? /2

Within a coherence domain the phase coherence increases as the number of particles in the domain is allowed to fluctuate. The more the uncertainty is taken up by fluctuation of the number of particles comprising a domain the more perfect is the coherence.

In the course of this work, I found that chemicals possessing a trace of water had a characteristic frequency pattern or signature. This is discussed in a later paragraph. Following my retirement, I had to close my university laboratory but, first I measured the characteristic frequencies of all the chemicals I had in stock before disposing of them. In the course of this, ELF resonances were found in the n-alkanes proportional to the chain length but, only when there was a trace of water present. In n-hexane, these resonances disappeared below about 14ppm of trace water. They were not present in 100% halogen saturated molecules.

If there are interactions involving the spectra of water and the characteristic molecular spectra of n-alkanes, these must be in the far-infra-red (FIR) rotational spectrum because this is the only place where n-hexane has any spectrum. For this reason it is widely used as a solvent in spectroscopy.

I needed to place some arbitrary restriction on the hundreds of rotational water lines which might otherwise have had to be considered. I noted that the rotational water lines at 28 µm (357 cm^{-1}), 47 µm (213 cm^{-1}) and 78 µm (128 cm^{-1}) can become coherent enough for use in a water vapour laser and concluded that these should also provide the necessary coherence for water "memory".

The wave numbers of the above three spectral lines for water and the tabulated FIR spectra for the n-alkanes were used. I postulated that the energy gap for the observed water resonances might be related to their differences. These were compared to the measured ELF resonances in n-hexane. as shown in Table 7.8.1. The mean of the FIR/ELF ratios is remarkably constant: 6.57 cm^{-1} per Hz_{ELF} or $1.97 \times 10^{11} \pm 0.16$ Hz_{FIR}/Hz_{ELF}

The above relates to effects of trace water in n-alkanes. The crucial question was whether the same argument could be applied to water laser lines in the absence of n-hexane and whether there were any measurable frequencies corresponding to differences between the FIR water lines and by implication to the interactions involved in homoeopathic potencies and water memory. These are listed in Table 7.8.2.

Table 7.8.1

Relation Between Far-Infra-Red Spectra and ELF Resonances for Trace Water in n-Alkanes

n-Hexanefrom tablescm^{-1}	Water-Laserlinescm^{-1}	Differences cm^{-1}	FIR Measured cm^{-1}	ELFMeasuredHz
385	357	28	28	4.141
403	357	46	46	6.793
450	357	93	93	13.11
485	357	128	125	19.16
403	213	190	192	26.51
485	213	272	263	42.52

To confirm this fractal effect, water was imprinted at frequencies between 0.001 Hz and 0.01 Hz (chosen for reasons of available frequency coverage). This water also showed corresponding resonances between 200 MHz and 2GHz giving a mean frequency ratio = $1.98 \pm 0.07 \times 10^{11}$ Hz_{FIR}/Hz_{ELF} . For the converse experiment, water was imprinted at frequencies between 200 MHz and 2GHz and showed resonances between 0.001 Hz and 0.01 Hz with a mean frequency ratio = $2.09 \pm 0.43 \times 10^{11}$ Hz_{FIR}/Hz_{ELF}. The worse standard deviation reflects the greater difficulties associated with the measurement of very low frequencies.

If 22 cm^{-1} is the fundamental resonance, the other difference wave numbers approximate to the integer ratios: 3,4,7,10, 11. The ratio of water laser differences to the measured GHz resonances is 1.722 ± 42 (SD ± 2.4%). The GHz to Hz ratio is $1.085 \pm 0.063 \times 10^{8}$ (SD ± 4.6%). This makes the ELF coherence propagate with a velocity 2.785 ± 0.093 (SD ± 3.4%) m/s. My measured velocity of coherence in water was 2.6 m/s. Note also that 1.42 GHz is the 21 cm resonance of molecular hydrogen. The frequency 0.384 GHz is the high band frequency of the heart acupuncture meridian and chakra, its lower frequency is 7.8Hz and this corresponds to a coherence velocity of 6.1 m/s. My measured velocity in the leg was 6 m/s.

The next thing to determine was what happened if an ELF was imprinted into the water by succussion. When water was imprinted by succussion with 10 Hz the ELF frequencies in Table 7.8.2 were replaced by sidebands at ±10 Hz, and the GHz and THz frequencies were replaced by proportionate sidebands.

When water was imprinted by succussion at 1 Hz. It was then serially diluted tenfold (1+9). The 1 Hz remained. When it was then successed the 1 Hz disappeared and was replaced by 10 Hz. This happened for the other frequencies and dilutions tested. In general: the original 1 Hz disappeared and was replaced after succussion by a frequency = 1 Hz × the dilution factor.

To determine whether potentisation is linear or discontinuous, water was imprinted by succussion at 1 Hz. Then, 10 ml aliquots were diluted in 10% steps and successed individually. The result was that the imprinted frequency remained at 1 Hz until a dilution ratio of 1:1.4. When the dilution was increased to 1:1.5, the frequency jumped to 1.5 Hz. For dilutions from here to 1:1.9 the frequency remained at 1.5 Hz. At dilution 1:2.0, the frequency jumped to 2 Hz. This was the general pattern at other dilution ratios with some exceptions. Although the 4-fold dilution gave 4 Hz so did a 5-fold

Table 7.8.2

Resonances for Water

Water LaserDifferences cm^{-1}	FrequenciesTHz	Measured in Water GHz	Measured in Water Hz
357 – 127 =230	6.90	4.03	36.8
357 – 149 =208	6.24	3.56	34.2
357 – 211 =146	4.38	2.65	22.6
211 – 127 =230 – 146 =84	2.52	1.42	13.3
211 -149 =208 – 146 =62	1.86	1.01	9.50
149 – 127 =230 – 208 =22	0.66	0.384	3.53

dilution. The 6-fold dilution gave 6 Hz but so did a 7-fold dilution. The 11-fold and 13- to 19-fold dilutions did not imprint any frequency at all. The 20- to 23-fold dilutions all gave 20 Hz; the 24- to 29-fold dilutions all gave 24 Hz, the 30-fold dilution gave 30 Hz. There were similar results for dilution ratios of 10, 100 and 1000 and similar exceptions. Thus, homoeopathic dilutions[9] must be carried out accurately (Smith, 2000).

Water was potentised by imprinting the total pattern of frequencies previously determined for thyroxin D15[10]. This was further potentised by serial dilution and succussion. The frequencies measured for each synthesised potency were exactly the same as those measured for potencies prepared from a “mother tincture” yet, my synthesised potencies had started from nothing but erased water. Importantly, there was no discontinuity at dilution D24 corresponding to Avogadro’s number, at which none of the original substance should remain. This is where chemists give up!

In allergy therapy, dilution is done with a syringe. In this case, effective succussion as detected by a change in frequency only took place when the dilution was sucked up through the needle ready for the next dilution which is where and when succussion by vortex takes effect.

Because of the fractality of frequency in coherent systems, it was possible to model molecules with H-bonded water bridges and measure their the ELF frequencies when immersed in a saline concentration chosen to give the correct velocity of coherence propagation. Table 7.8.3 shows the frequencies for molecular models of n-hexane. Note that this resonance frequency increases in proportion to length as is usual for a coherent system but, not in general where the larger the resonator, the lower is the frequency. The best fit corresponds to a hydrogen-bonded water chain extending the whole length of the molecule.

Table 7.8.3

Modelling n-Hexane

The first column lists the ELF signature frequencies for the chemical n-hexane, the second and third columns give the frequencies measured for molecular models of n-hexane in saline. A scaling of length 3cm/Å scales velocities by a factor 10^8 from the velocity of coherence in saline 3 m/s to the velocity of light in free space. 300 Mm/s. H-bonded water molecules joined to carbon atoms 1 and 6 match frequency pattern measured for n-hexane with trace water.

n-hexane +trace water	C_6H_{14}only	C_6H_{14} + 4 H_2OBridging $C_1 - C_6$
Hz	Hz	Hz
4.2	4.113	4.204
6.8	7.132	6.824
13	20.31	13.10
19.4	38.11	19.32
26	80.32	25.32
42		41.63

A frequency can be imprinted into water if it is excited by an A-field such as that from a toroidal coil oscillating at that frequency and subjected to succussion (impact). It can also be imprinted by a train of 7-unidirectional voltage pulses[11] or by a magnetic **B**-field – steady or alternating at any frequency less than that of the **A**-field. An electromagnetic field in which the **A** and **B** components are out of phase by ? will also effect an imprint. This can occur near power-lines and at certain distances from transmitters or in a resonant circuit.

The ‘Q-factor’ of a resonant circuit is the resonant frequency divided by the bandwidth between the half-power points on the resonance. It also equals the number of cycles in 2? time constants. For an exponential rise or decay of signal, the time-constant is the number of seconds required for the exponential to get to within 37% (1/exp) of the final value. It gets to within 0.2% of the final value in 2? time constants. The time-constant is also the time that the final value would be reached if the signal continued at its initial rate. For a 1 kHz resonance with a Q = 2500, the signal would take 2.5 seconds to build up to 0.2% of the final value. Failure to detect a resonance could be that one has not waited long enough.

Water can be imprinted by placing it within a resonator (Cardella et al., 2001). There is a threshold Q-factor required for this to occur. An LCR circuit was tuned to 384 MHz and the Q was adjusted with resistors until the threshold was found. This occurred between 392 and 470 and with a 2.5 ? resistor. Thermal electrons of 1/40 eV would develop 10 mA in this resistor and with the Q-factor this would be between 3.9-4.7 A. Since there is no power dissipation, it must be a Volt-Amps-Reactive situation with the voltage and current and the **A** and **B** fields out of phase by ?. This is a condition for imprinting into water. The **B**-field in the L-component from this current would be about 600 ?T, sufficient for an imprint at the resonant frequency.

7.8.4. A Theory for Water Memory

During attempts to measure frequency imprints in water by instrumentation and in work with electrically hypersensitive patients and with homoeopathic potencies, it was found that a potency or a water imprint would be erased if the geomagnetic field was shielded from it with a steel box[12]. The threshold magnetic field for erasure is ~1% of the geomagnetic field and is independent of imprinted frequency over at least 13-decades from 10^{-4} Hz to 10^{+9} Hz.

If erasure occurs when thermal energy exceeds the magnetic energy, this would occur for a spherical domain of 52.92µm diameter at ambient temperature, of 47.40 µm at -18ºC and 62.22 µm at +80 ºC.

For a direct measure of erasure dimensions, a drop of frequency imprinted water was placed between the jaws of a precision micrometer. Starting with a 1mm gap, the jaws were slowly closed until erasure occurred. The frequency imprint was present down to 109µm but erasure had taken place by 108µm. This was independent of the frequency imprinted over 13-decades from 10^{-4} Hz to 10^{+9} Hz. The threshold magnetic field erasure condition gives a domain diameter of 52.92µm compared with 108µm for the micrometer method. Therefore, it must be assumed that two domains (106µm) are required for wave function coherence to be maintained and the retention of a frequency imprint in water between two metal surfaces.

Imprinting a frequency into water affects the natural water resonances so if this model is correct, these must also resonate with coherence domains. The 62 cm^{-1} difference between laser water lines corresponds to a wavelength of 161 µm, this would correspond to a 'pearl-chain' of three 52.92 µm domains or 159 µm with present accuracy. If one water resonance can couple to a domain, fractality will couple the others to it.

We had shown in 1983 (Jafary-Asl et al., 1983) that living systems can respond to magnetic resonance (NMR) conditions, even at geomagnetic field strengths. Therefore, a frequency might be retained in water if proton precession becomes coherently synchronised to an applied alternating magnetic vector potential and then these coherent protons can generate their own internal magnetic field such as to satisfy proton NMR conditions. Such a process should be stable unless the domain is thermally broken up by removing the stabilising geomagnetic field.

The proton NMR condition gives the precession frequency nn = g B/2p where g is the gyromagnetic ratio 2.675 × 10^8 rad T^{-1} s^{-1}, B is the magnetic field and n is in Hz.

The magnetic field B at the centre of a magnetic dipole from a rotating charge is B = m_0 n e n / 2a where m_0 is the permeability of free space, n is the number of charges e involved, n is frequency (Hz) and a is the radius of the orbit. Whence, the number of charges n required is independent of frequency and n = 4p a / m_0 e g?

The water erasure threshold is 375 nT giving the radius of a coherence domain a = 26.46 µm. This makes n = 6.29´10^{12} which is the number of proton charges required to generate a magnetic field to satisfy NMR conditions. With two protons available for coherent synchronisation from each water molecule within sphere of 26.46 µm radius, 5.52´ 10^{15} protons should be available for taking up frequency imprints. Accordingly, water was imprinted successively with frequencies increased at 10 Hz intervals. There should have been enough protons to imprint 982 distinct frequencies. After 965 frequencies had been imprinted, no further imprinting was possible. At higher temperatures the domains are larger hence more protons should be available for imprinting. Heating this already imprinted water to 80ºC enabled imprinting to continue as far as 986 imprints. However, on cooling *all* these imprints self-erased. The pH of water expresses the availability of protons. It was found that whereas water at pH 5 would accept 935 frequency imprints, at pH 9 it would only accept 77.

I have shown that the basic arithmetical operations can be performed on frequencies imprinted into water and using somewhat similar arrangements that the basic reversible logic gates and their operations also can be implemented. Any reversible Boolean function can be computed by the reversible logic gates N (not), CN (control-not) and CCN(control-control-not). With reversible logic gates, knowledge of the output states enable one to determine the input states unambiguously; irreversibility leads to de-coherence and heat dissipation. These operations could be triggered by a train of seven voltage impulses acting like clock pulses and depend on the spatial arrangement of the water aliquots implying that there is a macroscopic wave function interaction (Smith, 2005b). The required voltages are low enough for nerve impulses to be able to trigger these operations.

7..9. Conclusions

In his 1967 paper, “Quantum Mechanical Concepts in Biology” Fröhlich (1969) got it exactly right even in the first words, “Quantum Mechanics – Biology”. He considered quantum mechanical concepts on a macroscopic scale with superconductivity a consequence of coherence, not of low temperature, of magnetic flux always being quantised and the possibility of the Josephson effect giving a frequency to voltage inter-conversion. The involvement of the magnetic vector potential is implicit in the wave equations which it enters like the chemical potential although he did not specifically discuss the possibility of living systems being sensitive to it.

Del Giudice et al. (in Fröhlich, 1988) remark that, “….the basic proposal of Fröhlich that density of electric polarization was the “order parameter” relevant for biological systems led them to a scheme for living systems with a finite size related to a non-vanishing temperature, the confinement of the internal EM field into filaments, low intensity coherent electromagnetic emission from living matter, magnetic flux quantization and Josephson-like effects, solitons on molecular chains and water electrets”.

Fröhlich predicted that long-range phase correlations in respect of biological order would persist over long distances in spite of thermal agitation. He assumed that the range would be limited by an absorption process and assumed that coulomb interactions would suffice. Del Giudice and Preparata considered that coulomb interactions would be screened by ion motion and that exchange of radiation between water molecule resonances could generate the necessary force. Fröhlich did not appreciate the possibility of coherence as a fundamental property of the ground state of water.

His metastable excited states in biomolecules having a very high dipole moment capable of strongly excited giant dipole frequencies (~100 GHz) and limit cycles have been found experimentally. Coherence propagates by diffusion and the soliton is a particular case of a metastable state; it is described by a non-linear diffusion equation. Coherence in water and metals appears to propagate by a diffusion process so it might be as solitons.

In her introduction to “Cooperative Phenomena” (Fröhlich F., 1973) Fanchon Fröhlich writes that, “It would be highly interesting, to attempt to impose the necessary oscillations by external means in the hope of influencing biological developments”. The excitation of organs to their correct frequency is the (unstated) aim of homoeopathic medications. Incidentally, chemicals such as allopathic medications must also have a chemical frequency signature associated with trace water (except for 100% halogen saturated molecules) and hence, they may also have a homoeopathic activity. In acupuncture, the needling spreads its endogenous frequency on the meridian throughout the body thereby making therapeutic use of the body’s endogenous frequencies.

The cessation of effects when cell concentration is high was observed in our *lac operon* experiments although, it was not then possible to measure simultaneously any coherent modes of oscillation. I have demonstrated effects with absorbers placed between two interacting living systems (tadpoles) which needed to remain in optical contact at yellow or shorter wavelengths for their synchronisation to persist.

A recent physics paper (Scully et al., 2003) may remove the restriction that Fröhlich needed for his systems which had to be pumped with energy from metabolic sources. Here, the addition of a quantum coherence term to the classical Carnot Heat Engine cycle provides a new parameter (information) which can be varied so as to increase the radiation temperature and enable work to be extracted from a single heat bath. If this concept is applicable to Fröhlich’s systems they could become their own heat bath and pump themselves. This may also relate to the thermodynamics of heats-of-mixing (Elia, 1999) and the informational content of the dilute solutions, homoeopathic potencies and frequency imprints that he measured.

An emerging view is that memory in living systems, DNA and water is *quantum holographic* and *syntactic* with the information encoded in *phase* (possibly the phase of a macroscopic wave function) and operations being modelled on computer *‘re-write’* systems. A quantum holographic system is the only system which places its image in the actual location of the object in space and time – essential for playing tennis for example (Marcer and Schempp, 1998). Recent work on computer *‘re-write’* systems looks towards a universal system with only a CREATE and a CONSERVE function which must be iterative and recursive from a ‘start-object’ to a ‘stop-criterion’ with a ‘null-potency’ or ‘empty-set’ rule (Rowlands and Diaz, 2002; Diaz and Rowlands, 2004).

The last two papers that Fröhlich wrote were on “The Stabilisation of Non-Linear Excitation in Biological Systems” (Fröhlich, 1988), and on “The Connection of Macro and Micro Physics” (Fröhlich, 1990). In the first, he summarised the developments since his 1967 paper to the Institut de la Vie noting that his second “*Green Book*” was now ‘in print’. He discussed deterministic chaos in respect of the problems of experimental reproducibility and noted a report that normal cells can exert control over those which have been transformed into cancer cells. In the second paper, which he was unable to present through illness occasioned by jet-travel, he emphasised that it is not possible to derive macroscopic properties by solving the many-body problem. He looked at muticomponent systems from the point of view of theoretical physics showing the importance of coherent frequencies giving long-range control and proposed experiments in terms of order-disorder transitions which would not require knowing the details of the interaction energy.

I think that one important question gets missed when Fröhlich’s work is considered. It is, **What is implicit in “Coherence”?** Biological systems have spatial coherence but apart from viruses they are not crystals. So the question becomes – **Coherence of what?** It is of course **Coherence of Frequency and Phase.** Fröhlich’s equations show what happens when two frequencies become equal. This implies that **Living Systems must be Frequency Sensitive – if they are to have Long-Range Order.**

7.10. Acknowledgements

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