The Biological Basis of Low Level Laser Light Therapy (3LT™)

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Summary

The field of low-level laser therapy (3LT™) is growing rapidly, but there is no consensus on the therapeutic mechanisms involved. One reason for this is that much of the basic research on the biology of light has been reported in non-English books and journals or in specialized technical publications. A second reason is that a vast area of Soviet research, which thrived for more than half a century and produced a wealth of important experimental and theoretical discoveries, was almost completely ignored in the West. Moreover, studies of light and light therapies have simply been outside of the pharmacological paradigm that is the main focus of western biomedicine. This summary aims to demystify the biological effects of laser light by reviewing the accomplishments of key scientists from around the world: Alexander Gurwitsch, Herbert Fröhlich, Fritz-Albert Popp, Guenther Albrecht-Buehler, and Mae-Wan Ho and their colleagues. All organisms, including humans, emit a glow that is too faint to be detected with the eye, but that can be measured precisely with photomultipliers that amplify weak signals millions of times. Key studies have shown photonic interactions between cell populations that are optically coupled (e.g. via quartz windows or an air gap) but chemically separated so that communications via chemical mediators such as hormones, growth factors and neurotransmitters cannot take place. On the basis of the literature reviewed here, it is concluded that the cells in the human body, and the body as a whole, both emit and absorb coherent biophotons; these photonic emissions and absorptions play key roles in the regulation of cellular and physiological processes, including the healing of injuries and diseases. One important role of light is in activating cell division, a process that is essential in wound healing as it provides for the replacement of damaged cells. Light in visible and near-visible regions of the spectrum may stimulate wound healing by attracting white blood cells and fibroblasts to the sites where they are needed to kill bacteria, remove damaged cells, and carry out repair and replacement. It appears that optimal results with light therapy take place when the light is of low intensity (does not heat tissues), short duration, and pulsed on and off. A part of the review covers quantum physics as it applies to living matter, and the role of biophotons in energizing and coordinating physiological processes.

Introduction

Various forms of light therapy can be traced to Biblical times and to virtually all ancient cultures.[1] During the last century light therapies of various kinds were pioneered by Edwin Babbit, M.D., Dinshah Ghadiali, Kate Baldwin, M.D., Harry Riley Spitler, M.D., O.D., Dr. Norman Shealey, M.D., Ph.D., Jacob Liberman, O.D., Ph.D., and Dr. John Ott, to name a few. It is well known that lack of sunlight is associated with specific maladies such as rickets and osteomalacia, which are caused by insufficient synthesis of Vitamin D. And it is also established that specific wavelengths of sunlight trigger the germination of seeds and their subsequent growth into the mature plants that provide nourishment to all animals on our planet. In other words, light is vital to life.

The field of Low Level Laser therapy (3LT™) is growing rapidly, with literally thousands of articles published in the clinical literature. This is exciting for those who have witnessed the remarkable therapeutic benefits of 3LT™.

It is often stated that it is not known how the laser affects living tissues. The reason for this statement is that few clinicians and researchers are aware of the extensive research that has been done in the fields of biophysics, biophotonics, photobiology and quantum biology during the past 80 or so years. The details of this research are obscure for a variety of reasons:

- Much of the work has been published in non-English books and journals, particularly German, Russian and other Slavic languages.
- Western biomedicine, with its emphasis on pharmaceutical interventions, has given little attention to the therapeutic applications of various forms of light.
- A vast area of Soviet scientific research, which thrived for more than half a century and produced a wealth of important experimental and theoretical discoveries, has been almost completely ignored in the West.
- A clear picture of the effects of laser requires an appreciation of our emerging understandings of the quantum physics of coherent laser light and the corresponding quantum properties of living tissues.
- Much of the information on this topic has been published in diverse specialized technical journals.

There is a need to clarify the effects of laser light on living tissue as medical texts are being re-written to include the clinical benefits of 3LT™ and its underlying scientific basis.

A number of texts deal with the fundamentals of 3LT™.[2] Thorough and scholarly summaries of recent biophotonic research have been published by Marco Bischof in an extensive book in German[3] and in a summary in English.[4] Bischof has also published an extensive bibliography on biophotons.[5] Ho has written a valuable summary in English[6] and important Russian research has been summarized by Voeikov.[7] The role of biophotons in biocommunications has been reviewed by VanWijk.[8] Here we review research on biophotonics, biophysics, photobiology, and quantum biology and describe how this science provides a logical basis for the effects of 3LT™.

Those experienced in the scientific process will be aware that aspects of this research continue to be controversial, as is the case in all branches of science. However, when the results are taken together, an inescapable conclusion emerges: **The cells in the human body, and the body as a whole, both emit and absorb coherent biophotons; these photonic emissions and absorptions play key roles in the regulation of cellular and physiological processes, including the healing of injuries and diseases.** The information summarized here is leading to a detailed scientific explanation of how 3LT™ affects living systems, and why coherent light has more significant biological effects than ordinary or incoherent light, such as that produced by a tungsten filament or light emitting diode (LED).

We begin by summarizing important early Russian work done by Alexander Gurwitsch and colleagues. We then place that work in a modern context by summarizing discoveries in the fields of non-linear dynamics and quantum physics.

Alexander Gurwitsch: cells emit light

The Russian embryologist and histologist, Alexander Gurwitsch (1874-1954) is in many ways the "father" of modern biophotonics. From the 1920's to the 1940's, Gurwitsch and his colleagues at the Leningrad Institute for Experimental Medicine and the Academy of Medical Sciences in Moscow carried out pioneering research on the emission of light by cells.[9]

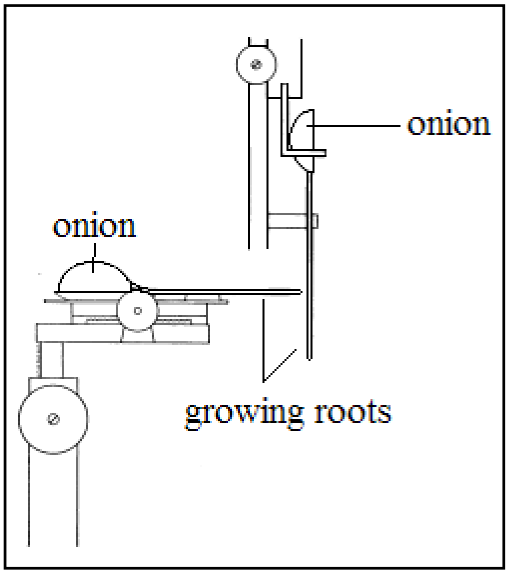


Figure 1.
Gurwitsch's classic "onion root" experiment. Using this set-up, Gurwitsch showed in 1926 that the growing tip of an onion emits a form of radiation that stimulates cell division in a nearby root tip. Gurwitsch termed this "mitogenic radiation" since it stimulated mitosis. This was the first demonstration of light emission from cells.

Gurwitsch began studying the kinetics of growth in plants in 1911.[10] The early work revealed that some unidentified non-chemical factor must be involved in regulating cell division. The discovery of the role of light emerged from Gurwitsch's classic "onion root" experiment (Figure 1). Using this set-up, Gurwitsch showed in 1926 that the growing tip of an onion emits a form of radiation that stimulates cell division in a nearby root tip. The regulatory factor traverses a 1.5 to 2 mm air gap between the two root tips. The effect is still present when a quartz window is inserted between the two root tips, so the stimulating factor cannot be a diffusing chemical. Gurwitsch termed this factor "mitogenic radiation" since it stimulated mitosis. This was the first demonstration of light emission from cells. Gurwitsch proved that the central event of life–cell multiplication–could not come about unless the cell acquired a mitogenetic photon. He predicted that the "mitogenic-laser field" emitted by a cell would extend beyond the border of the individual cell, and that its intensity would be greatest along the axis of the movements of the chromosomes during cell division.[11] We shall see that the conclusions reached by Gurwitsch have been confirmed by modern investigators using equipment that was unavailable to the Russian pioneers in the study of light.

It was soon discovered that yeasts also emit light. Gurwitsch suspected that mitogenic radiation was in the ultraviolet part of the spectrum, because it was transmitted through quartz but not through ordinary glass. The early years of this research there was no way of directly measuring the properties of mitogenic radiation.

The work of Gurwitsch is a classic example of a research method known as the "biological assay." It is discovered that some unknown factor influences a biological system in a reproducible manner, but at first, the only way to study the effect is with the living system. For example, Gurwitsch's research utilized plant cells as radiation detectors. Eventually the use of the biological assay enables researchers to systematically narrow the cause of the effect and, finally, identify it exactly. This is, for example, the process that has led to the identification of a number of vitamins and hormones. Of particular importance in the work of Gurwitsch and those who followed are demonstrations of photonic interactions between cell populations that are optically coupled (e.g. via glass or quartz windows) but chemically separated so that communications via chemical mediators such as hormones, growth factors and neurotransmitters cannot take place.[12] There is no question of the importance of chemical communications taking place in organisms, and of their vital roles in physiological regulations. But photonic interactions are also taking place, and also have key regulatory roles. Chemical communications are relatively slow, as they involve diffusion of regulatory substances, whereas photonic biocommunications obviously take place at the speed of light.

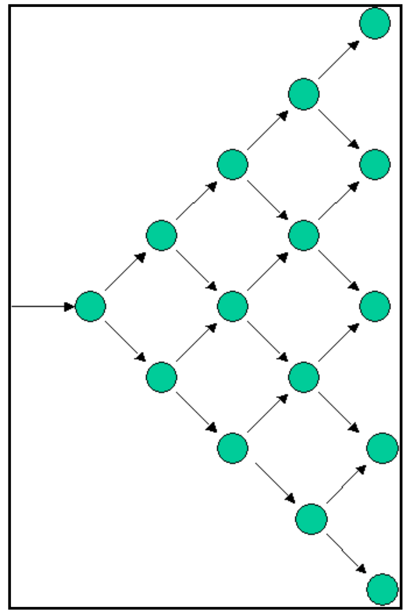
Mitogenic radiation is an important concept in relation to 3LT™ because injury and disease obviously result in damage to cells, and damaged cells must be replaced by cell division. This is one of the most significant processes involved in injury repair. Hence the clinical importance of mitogenic or mitosis-inducing radiations described by Gurwitsch. The fact that certain kinds of light can stimulate mitosis is fundamental to understanding 3LT™.

Mitogenic radiation attracted the attention of scientists worldwide, and there was a "Golden Age" of mitogenic research that led to publication of a thousand papers and several books on the subject. Rahn summarized this work in English in 1936.[13] While many studies confirmed the role of light in regulating cell division in plants, a few scientists were unable to replicate the effect. As often happens in science, the few "disproving papers" received widespread attention, and interest in mitogenic radiation declined in West European countries and the USA. The inability of some investigators to replicate the phenomenon was due to obvious experimental errors, such as the use of immature yeast cultures, even though Gurwitsch and others had repeatedly pointed out that early stage yeast cells are not sensitive to external photons. Research in Eastern Europe and Russia continued, although progress was greatly slowed by World War II.

In 1938, Gurwitsch found that the absorption by a living cell of a photon with energy around 5 eV initiates mitosis. This result was confirmed half a century later by Kozlov and Magaladze.[14] This low level radiation had a surprising property. Gurwitsch did experiments with a rotating slotted wheel. The wheel was placed between a light source and the cells. At certain frequencies of wheel rotation the mitogenic effect was observed at much shorter exposure times or larger distances between the source and the cells, than without intermittence.[15] **In other words, the efficiency of the mitogenetic effect significantly increases if irradiation of the cell is intermittent or oscillatory. This discovery provides the biological basis for the therapeutic use of different pulsation**

frequencies, such as provided by some lasers. We will see below that more recent studies of Albrecht-Buehler confirm that pulsing light is more effective in cell-cell communication than steady light.

Further work by the Russian group showed that a single photon can trigger a reaction in one cell that causes the emission of several photons.[16] These then trigger photon emissions in other cells, and the effect spreads from one cell to many cells, like a chain reaction. These are called high-speed branched-chain processes or *avalanche effects* (Figure 2). They account for the fact that a tiny signal can be multiplied to cause a rapid and regenerative flow of energy throughout a biological system.



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Another aspect of the way cells respond to light is called *hysteresis*. The change induced by light is not linear, but depends on the system's *prior history*. This is an important principle in relation to healing, since it accounts for the tendency of a tiny stimulus to restore a tissue to its original healthy condition following damage.

After World War II sensitive light detectors called photomultipliers became available. In the late 1940's, Soviet scientists began using photomultipliers to study light emissions from organisms. For example, Mamedov and colleagues studied over 100 different species of organisms.[17] Photon emission was present in about a third of the algae, bacteria, fungi and insects examined. In higher plants and vertebrates, all species investigated emitted light. This research was not published in English. In the 1950's, Colli and Facchini in Milan were the first in the west to use photomultipliers to confirm Gurwitsch's discoveries.[18] These researchers established that living things emit biophotons in the spectral range of 650 to 390 nm, i.e. from infrared to ultraviolet, including the visible wavelengths. In the late 1960's and early 1970's, an Australian biochemist, Quickenden, began systematic research on biophotons using photomultipliers sensitive enough to detect a single photon.[19] This research revealed that some of the species that had given no detectable luminescence in the Mamedov studies were actually emitting light.[20] This was soon confirmed by Wang et al.[21]

The discovery of avalanche effects and hysteresis in living systems ties in with modern developments in non-linear dynamics that were unknown to Gurwitsch and colleagues. Much of the confusion about the use of therapeutic lasers stems from attempting to look at laser effects from a Newtonian mechanistic perspective that has now been supplanted by non-linear dynamics and quantum physics.

Non-linear dynamics.

There is an important distinction between linear and non-linear systems. Linear systems are Newtonian. For example, Newton's Laws of Motion state that objects at rest tend to remain at rest and objects in motion tend to remain in motion until a force is exerted on them. Newton's laws were extremely successful, as they could accurately predict the orbits of the planets around the sun, the paths of projectiles on earth, and the oceanic tides, among many other things. Newton's laws were so effective that for several centuries after their discovery, physics consisted largely of demonstrating how Newtonian mechanics accounts for the motion of virtually any object. This study became the branch of physics known as *kinematics*.

When these concepts are applied to living systems and to medicine, we tend to think that the absence of a clinical effect may mean that we have not applied enough force or our dosage is too low. Linear systems tend to respond slowly to large stimuli, and larger stimuli are expected to produce larger responses. While this logic is successful some of the time, those successes mask a more subtle non-linear aspect of living systems. Non-linear systems actually respond rapidly to tiny stimuli.

A well-documented example is provided by the auditory system. It has been discovered that the smaller the sound stimulus, the larger the response of the hair cells in the inner ear.[22] This is, of course, counter intuitive. Most of us operate most of the time in a Newtonian mode, in which it is obvious that greater force or effort will accomplish more. It is not always easy to grasp that there are situations where less energy will produce a larger effect. Much of the confusion around 3LT™ stems from a lack of appreciation of the well-established non-linear aspects of living systems.

At the time Gurwitsch was describing chain-reaction or branched-chain processes in living systems there was an established physiological principle known as the Arndt-Schultz Law:

- Small doses or forces or energies stimulate functions in the living organism with little or no inhibition.
- Larger does or forces or energies initially stimulate and then equally inhibit function.
- Very large forces or energies dramatically stimulate function for a very short time only and then dramatically and for long periods of time inhibit, even to the point of death.

We now have a much more sophisticated understanding of linear vs. non-linear phenomena in living systems. Living systems are profoundly non-linear, as was documented by the research of Ilya Prigogine (Nobel Prize 1977).[23] The non-linear thermodynamics of Prigogine begins to explain the behavior of the highly ordered structures found in biological systems.

These conclusions are significant because some have suggested that a low level laser can have no biological effect because the energy levels are too low to heat the tissues. The work of Gurwitsch and those who confirmed his results, as well as modern non-linear dynamics and quantum coherence (see below) show that the opposite is true: very low levels of light or other forms of energy can produce significant biological effects, and these responses can *avalanche* through the organism from atom to atom, molecule to molecule, and cell to cell, creating a chain reaction of effects. The results obtained by Gurwitsch and colleagues can also be better understood from the perspective of quantum physics.

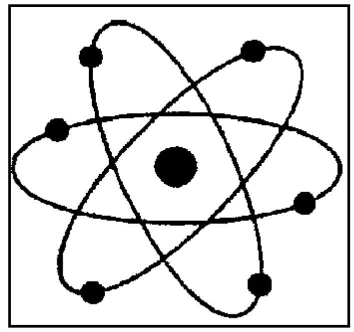

Figure 3.
Most texts model atomic structure after the solar system, with the electrons orbiting the nucleus much like the planets orbit the sun.

Introducing quantum physics

Quantum physics is regarded as "the most precisely tested and most successful theory in the history of science."[24] Quantum mechanics is distinctly different from the older and more familiar Newtonian mechanics, and gives a more precise picture of the structure and behavior of matter, including living matter. Understanding quantum physics is challenging because it deals with a subatomic realm that we usually cannot experience directly. However, over the past 20 years, the scale at which quantum effects can be observed has become increasingly large. Recent experiments have shown quantum behavior of molecules such as fullerenes, composed of 60 atoms.[25]

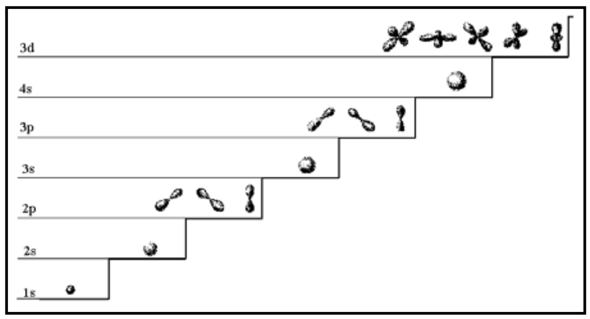

Figure 4.
In quantum physics the atom is viewed as being composed of electrons that are in different generalized concentric volumes of space called orbitals (not orbits). The orbitals are volumes where there is a statistical tendency for the electrons to be located most of the time. The atomic volumes occupied by the different orbitals are such that a pair of electrons can exist in each orbital without encountering electrons from other orbitals. The drawing shows the stepwise increase in energy as electrons fill the various orbitals, which are designated by 1s, 2s, 2p, 3s, etc. Larger and larger atoms are built up by the addition of electrons in orbitals following a defined "filling order" beginning with the 1s orbital.

First, what is a quantum? Answering this question takes us to our modern understanding of the structure of the atom. Most texts present a Newtonian model of atomic structure, in which the nucleus is at the center and the electrons travel around the nucleus in orbits, much like the planets revolve around the sun (Figure 3). Newton's laws of motion were instrumental in enabling mathematical astronomers to predict the exact location of all of the planets and the moon with respect to the earth and sun at any given time in history. The enormous success with the "clockwork universe" model gave rise to *determinism*. In the early 1800's, Pierre Laplace proposed that, given knowledge of all the forces of nature and the status of the bodies of which nature is composed, all past, present, and future events could be determined exactly.

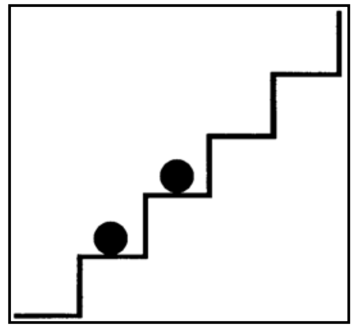

Figure 5.
The energetic structure of an atom compared to balls on a flight of stairs. You can place a ball on the first step, or the second step, or the third step, but not on the 2 ½ th step. Each step represents a quantum energy level.

Quantum physics put an end to determinism. A key discovery was due to Heisenberg, who received the Nobel Prize in physics in 1932. Heisenberg's Uncertainty Principle states that if we know the position of a particle with total accuracy we can know nothing about its momentum--and vice versa. A consequence is indeterminacy at the quantum level. We cannot view the electrons in an atom as discrete Newtonian particles in definable and predictable orbits. Instead, electrons are better viewed as energetic entities such as waves or "wavefunctions". A wavefunction is a mathematical expression of the statistical probability that a particle will have a certain set of properties.

Hence, while the analogy of the atom to the solar system is easy to grasp, quantum mechanics shows that the orbit model is completely incorrect. A consequence of the Uncertainty Principle is that we do not really know exactly where the electrons in an atom are located and what they are doing. Instead, in quantum physics the atom is viewed as being composed of electrons that are in different generalized volumes of space called orbitals (not orbits). The orbitals (Figure 4) are volumes where there is a statistical tendency for the electrons to be located most of the time. Note that each of the three 2p and 3p orbitals shown in Figure 4 can contain up to 2 electrons.

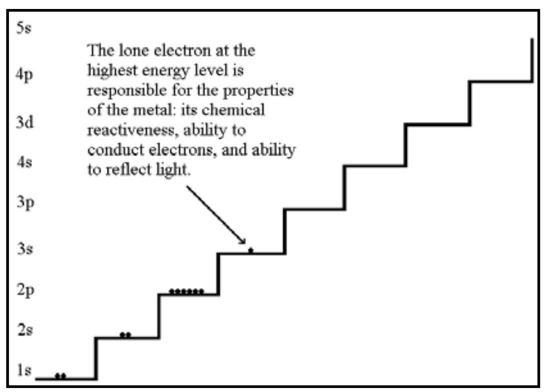

Figure 6.
The metal, sodium, has 11 electrons, which are organized into 4 different energy levels, 1s, 2s, 2p, and 3s. The most energetic electron, located in the 3s orbital, is the electron that gives sodium its properties, such as its chemical reactiveness, ability to conduct electrons, and reflect light. This reactive electron is called the *valence electron*.

Quantum mechanics began with studies of Max Planck, reported in 1900. By studying the law of blackbody radiation, which he had discovered, Planck detected in optical phenomena a discontinuous process totally unknown to classical physics. A few years later, Einstein expressed his hypothesis that radiant energy consists of individual particles, termed "quanta", approximately in the same way as matter is made up of particles such as atoms. Planck received the Nobel Prize for Physics in 1918, and Einstein was similarly honored in 1921.

The basic discovery is that the electrons in atoms can only have discrete energy values. Moreover, electrons, atoms and compounds absorb and radiate light of certain sharply

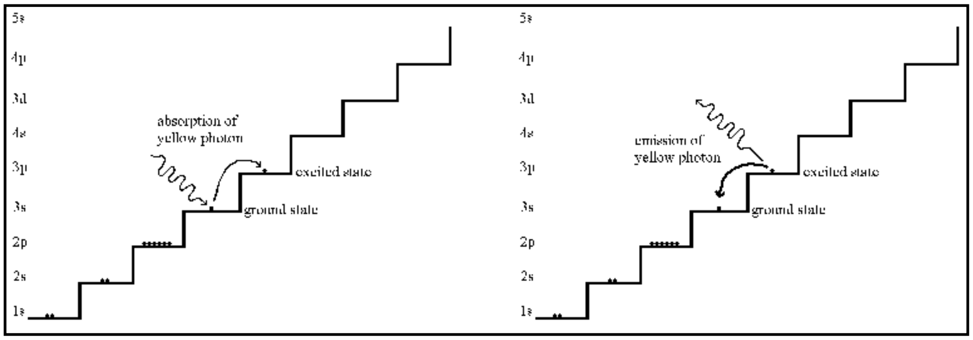

Figure 7.
When the valence electron in sodium absorbs a yellow photon, designated by the wavy arrow to the left, the electron acquires enough energy to jump from its *ground state* to the next energy level or orbital, which is termed the *excited state*. After a short time, the electron re-emits its yellow photon, and drops back down one step, to the original or ground state energy level, as shown to the right. This process is the basis for the sodium vapor lamp, which produces a yellowish light.

defined energies or frequencies. A simple analogy is provided by a flight of stairs (Figure 5). You can place a ball on the first step, or the second step, or the third step, but not on the 2 ½ th step. For example, a photon can give its energy to an electron, and the electron will no longer be able to occupy the same energy level. It must "jump" to a higher orbital. Different frequencies or colors of light have different amounts of energy, so the increase in the occupied energy level of the electron correlates with the color of light absorbed.

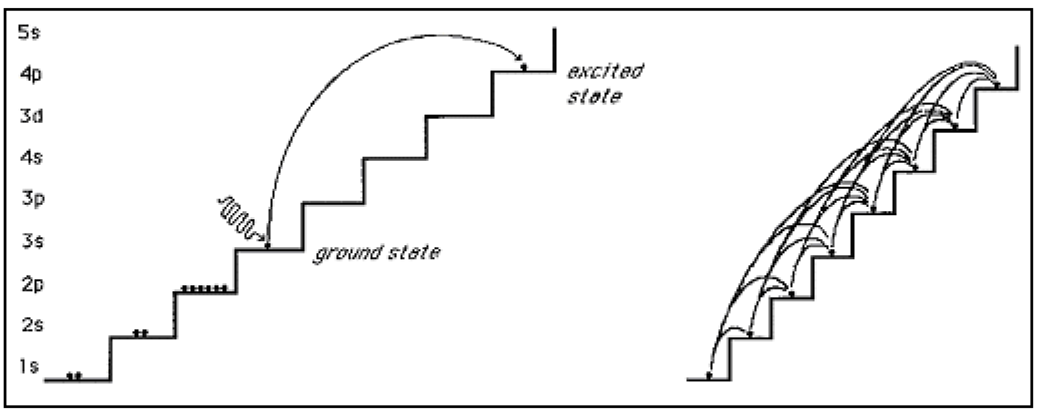

Figure 8.
Left, while the yellow light has the energy needed to kick the sodium electron up one quantum level, as shown in Figure 5, more energetic light, in the far ultraviolet region, will kick the valence electron from the 3s to the 4 p level. The diagram to the right shows that there are many energy levels available in an atom, and electrons can jump between the different levels when photons of the appropriate color (frequency) are provided.

An example is shown in Figure 6. The metal, sodium, has 11 electrons, which are organized into 4 different energy levels, 1s, 2s, 2p, and 3s. The most energetic electron, located in the 3s orbital, is the electron that gives sodium its properties, such as its chemical reactiveness, ability to conduct electrons, and reflect light. This reactive electron is called the *valence electron*.

Figure 7 shows how light interacts with the valence electron. A yellow photon is absorbed by the valence electron and acquires enough energy to jump from its *ground state* to the next energy level or orbital, which is termed the *excited state*. After a short time, the electron re-emits its yellow photon, and drops back down to the original or *ground state* energy level.

While yellow light has the energy needed to lift the sodium electron up one quantum level, more energetic light, in the far ultraviolet region, will cause the valence electron to jump from the 3s to the 4 p level, as shown to the left in Figure 8. (Note a subtlety in the drawings. The ultraviolet photon in Figure 8 has its peaks closer together; a way of indicating that it has a higher frequency and a higher energy than the yellow photon in Figure 7). Atoms have many different energy levels available to them. Transitions can and do occur between all of the different energy levels, as shown to the right in Figure 8. Indeed, virtually all of our knowledge of the structure of atoms and molecules is based on measurements of such light-induced energetic transitions, a field known as spectroscopy.

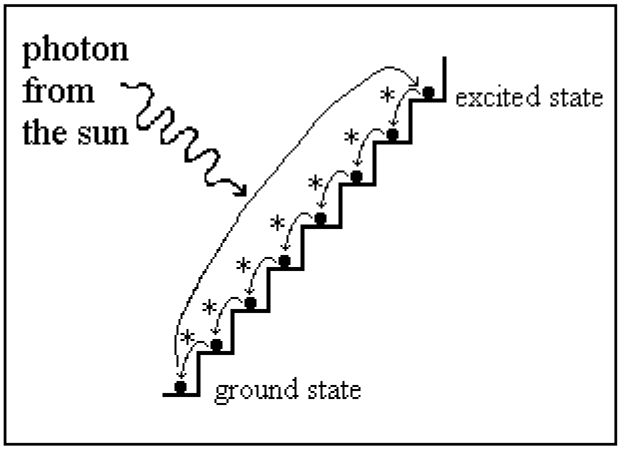

Figure 9.
The overall energetic scheme in living matter. Photons from the sun are absorbed by chlorophyll molecules in plants. Electrons in the chlorophyll become excited and jump from chlorophyll to chlorophyll molecule until they reach a reaction center where they are coupled into the plant's biochemical machinery. The excitation energy is then stored in stable chemical bonds in molecules such as starch. When animals eat the plant, the chemical bonds are broken in a controlled process, releasing the energy step by step to operate the various processes necessary to life: growth, movement, thought, sensation, excretion and so on. The energy released from chemical bonds as the electrons drop from the excited state back to the ground state is designated by * in the drawing.

Introduction to quantum biology

> *If a photon, ejected by the sun, interacts with an electron of a molecule on our globe, then the electron is raised to a higher energy level, to drop back , as a rule within 0.00000001 to 0.000000001 sec., to its ground state. Life has shoved itself between the two processes, catches the electron in its high-energy state, and lets it drop back to the ground level within its machinery, using the energy thus released for its maintenance.*
>
> ~Albert Szent-Györgi[26]

The above quote, from one of the founders of modern biochemistry, summarizes the quantum basis for the overall energetics of living systems. Photons from the sun are absorbed by chlorophyll molecules in plants. Electrons in the chlorophyll become excited and jump from one chlorophyll molecule to another until they reach a *reaction center* where they are coupled into the plant's biochemical machinery.[27] The excitation energy of the electron is then stored in stable chemical bonds in molecules such as starch. When an animal eats the plant, the chemical bonds are broken in a controlled process, releasing the energy step by step to operate the various processes necessary to life: growth, movement, thought, sensation, excretion, reproduction and so on (Figure 9). The energies released from chemical bonds as the electrons drop from the excited state back to the ground state are designated by * in the drawing.

Biochemistry and molecular biology have described the various molecules in living systems, but not the precise ways they process electronic excitation. It is well known that adenosine triphosphate (ATP) is used as an energy source in plants and animals, but this is only a part of the story. For example, it was known in 1967 that the ATP consumption by active muscles is not sufficient to power them.[28] This finding was confirmed,[29] but the mystery remains. Albert Szent-Györgyi was convinced that:

> *Life is too rapid and subtle to be explained by slow moving chemical reactions and nerve impulses.*
>
> ~Albert Szent-Györgyi

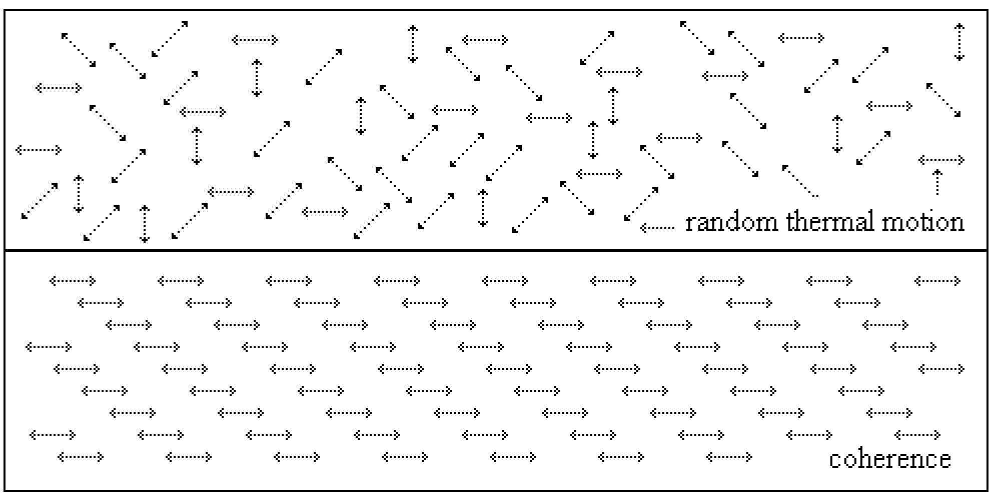

Figure 10.
At ordinary temperatures the atoms in matter exhibit uncoordinated or random motions, and the velocity of these motions increases with temperature (upper panel). However, when substances are cooled to very low temperatures, the behaviors of the individual atoms or molecules merge (bottom panel). This is called a *collective state*. Unusual properties such as superfluidity and superconductivity begin to appear. All of the atoms or molecules behave as though they are connected to each other. Their motions are coherent and correlated, and this creates greater than normal fluidity and virtually no resistance to the flow electricity. This happens in liquid helium at temperatures close to absolute zero, and in plasmas. We shall see that it is thought that this also happens in living matter.

This and other problems created an "energy crisis" in biology that was discussed at length at a major symposium in 1973[30]. The problem can be stated simply: we know that there is usually plenty of energy available to do what we wish to do. For the biochemists the problem was to explain how energy gets to the places within the cell where it is needed for activities such as muscle contraction and nerve conduction. The study of biophotonics and biological coherence has cleared up some of the confusion about this problem by providing a physical mechanism for the accumulation and storage and rapid mobilization of energy by living things. To understand this scheme in more detail, we need to describe quantum coherence as it occurs in lasers and in living matter.

At ordinary temperatures the atoms in matter exhibit uncoordinated or random motions, and the velocity of these motions increases with temperature (upper panel in Figure 10). However, when substances are cooled to very low temperatures, the behaviors of the individual atoms or molecules merge (bottom panel in Figure 10). This is called a *collective state*. Unusual properties such as superfluidity and superconductivity begin to appear. All of the atoms or molecules behave as though they are connected to each other. Their motions are coherent and correlated, and this creates greater than normal fluidity and virtually no resistance to the flow electricity. This happens in liquid helium at temperatures close to absolute zero, in plasmas, and in lasers. We shall see that it is thought that this also happens in living matter.

The technical term for this phenomenon is *Bose-Einstein Condensation*, named after Satyendra Nath Bose (1894-1974) and Albert Einstein. Bose was an Indian mathematician and physicist who wrote a paper in 1924, *Planck's Law and the Hypothesis of Light Quanta*[31] that led to a collaboration with Einstein. Bose had developed a statistical theory for light, and Einstein showed that the same rules applied to atoms, as in a gas. The result of the collaboration was a mathematics, *Bose-Einstein statistics*, that describes the gas-like qualities of both electromagnetic radiation and collections of coherent electrons or atoms, sometimes referred to as a *superatom*. The theory described the behavior of a group of indistinguishable particles in the same energetic state, and accounts for the cohesive streaming of laser light and the frictionless creeping of superfluid helium. Technically, the Bose-Einstein condensate is a dense collection of bosons (elementary particles or atoms with integer spin, named after Bose).

Bose-Einstein behavior can take place at room temperature in the laser and in the human body. The laser followed from the discovery of the Maser, a device that produces coherent microwaves. The first papers about the maser were published in 1954 as a result of investigations carried out simultaneously and independently by Townes and his co-workers at Columbia University in New York and by Basov and Prokhorov at the Lebedev Institute in Moscow. We mention the Moscow work because it is important, once again, to acknowledge the pioneering Russian research on lasers and the therapeutic applications of lasers. Unfortunately, scientists in the west have tended to disregard significant Russian research, including that of Gurwitsch. This is another cause of the current confusion about laser therapeutics. In the laser, atoms are energized to vibrate and emit light, and a clever mirror trick is used to synchronize the vibrations into a collective state or quantum coherence.

A number of physicists determined that coherence in metals and plasmas and lasers is a state in which electrons or atoms become capable of both collective action and individual freedom. Specifically, fluctuations may be split into two components. One component is associated with the organized oscillations of the system as a whole, the so-called "plasma" oscillations. There are long-range correlations in the positions and oscillations of electrons or photons or atoms–they interact over a distance. The other component is associated with the random thermal motion of the individual atoms or photons or electrons, and shows no collective behavior. David Bohm and colleagues published a series of 3 important papers on this subject in 1951, 1952 and 1953.[32] This concept led to major advances in physics. Mae Wan Ho describes this phenomenon as “quantum jazz:”

> *Think of a gathering of consummate musicians playing jazz together (‘quantum jazz’) where every single player is freely improvising from moment to moment and yet keeping in tune and in rhythm with the spontaneity of the whole. It is a special kind of wholeness that maximizes both local freedom and global cohesion.*
>
> ~Mae-Wan Ho[33]

Quantum coherence in biology

These may seem like esoteric phenomena, but they become real to us in peak athletic or artistic performances. A perfect performance requires precise cooperation and coordination and power supply to all bodily systems while, at the same time, allowing the individual parts to spontaneously fine-tune their behavior in response to the demands of the moment or unexpected changes in the local environment. Without such fine-tuning, the smallest disturbance, such as a small un-evenness on a surface, could compromise the whole effort. Quantum Jazz, then, reveals itself in the Olympic Gold Medal, the world record, or the personal best performance.

> *Fundamental [questions include] how we are to account for the unitary nature of a living organism: the way it responds as a whole to any stimulus – as if every part of it knew what every other part is doing. Life has this holistic property at any scale, from an amoeba to an elephant, and whether or not it has a nervous system. Quantum physics provides us with an exact science for which such a holistic view is only natural. It lets us understand how the wavefunctions of protons and electrons which make up an atom or molecule sink their individuality to a common wavefunction: an irreducible holistic property. I want to persuade you that a living organism is a quantum being, with a unified wavefunction, in the same way that an atom is.*
>
> ~Roger Taylor[34]

The distinguished physicist, Herbert Fröhlich (1905-1991) was one of the leading theorists in the study of the collective state and Bose-Einstein behavior in nonliving crystalline materials such as superconductors, superfluid helium, and lasers. In about 1938, a friend told Fröhlich that animal cell membranes have a significant electrical potential of nearly 100 mV across them. Fröhlich was astonished by this when he learned how thin cell membranes are (10^{-6} cm). Physicists know that there are few materials that can maintain such a large voltage across such a thin layer without breaking down.

Fröhlich wondered if some of the quantum phenomena he had been studying in inorganic materials might apply to biological systems. As described above, superconductors, superfluids and lasers display long-range phase correlations or coherent modes, in which the movements of individual electrons or photons or atoms become coupled together. Fröhlich realized that under appropriate conditions the individual components of the molecular arrays in the cell membrane should vibrate in unison, or coherently.

> *'Coherence' is generally understood as 'wholeness', a correlation over space and time. Atoms vibrating in phase, teams rowing in synchrony in a boat race, choirs singing harmony, troops dancing in exquisite formations, all conform to our ordinary notion of coherence.*
>
> ~Mae-Wan Ho[35]

In 1968 Fröhlich predicted that the collective processes taking place in living organisms would enable them to behave like superconductors working at body temperature. Perhaps much of the metabolic energy produced within the body is stored in the form of coherent electromechanical vibrations in highly ordered structures such as cell membranes. This form of energy would be highly mobile: it could be transferred from place to place virtually instantaneously with great efficiency and virtually no loss. In terms of physics, the energy would be in a wavefunction; it would be *delocalized*.

This concept of energetics is congruent with the experiences of highly trained athletes or other performers, who are capable of remarkable feats that require the coordinated or integrated operation of tissues and systems throughout their bodies. Oschman published a book in 2003 to describe quantum coherence and its applications in therapeutics and human performance.[36]

On the basis of quantum physics, Fröhlich predicted that these collective vibrations would be in the frequency range of light, so the structures should give off visible and near-visible coherent or laser-like light. This light should move about within the organism and also be radiated into the environment. In 1968 Fröhlich published a paper suggesting that this might be a mechanism for energy storage and communication in living systems.[37] Note the similarity of this concept with that of AG Gurwitsch, who referred to the "mitogenic-laser field" emitted by a cell that extended beyond the border of the individual cell to affect other nearby cells.

By 1988, leading scientists from around the world had explored and confirmed Frohlich's ideas and described their significance in a wide range of biological systems.[38]

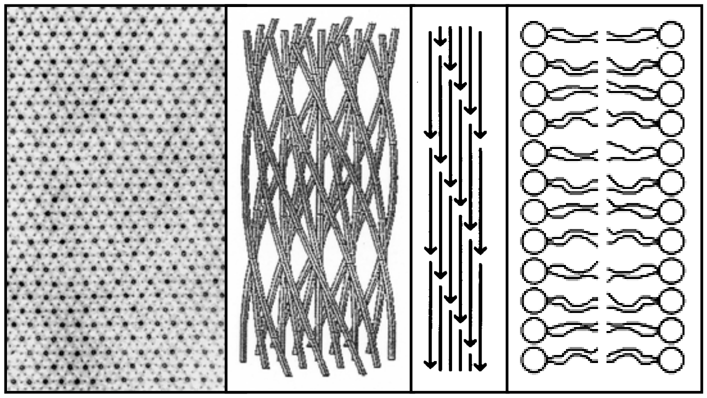

Figure 11.
Highly ordered or structurally coherent domains in living tissues. From the left, a cross section showing the highly ordered contractile proteins in muscle; second from left, the close packing of DNA in the nucleus of the cell; third, the array of collagen molecules in connective tissue including bone; right, the arrays of phospholipids in cell membranes.

In 1996, Ho pointed out that the high degree of molecular order found in cell membranes is also characteristic of many other tissues in the human body, including the DNA in chromosomes, all proteins, especially cytoskeletal proteins, muscle proteins, and the collagens of connective tissues.[39] The high degree of order in these materials is shown in Figure 11. These materials are technically known as liquid crystals; materials that have properties of both solids and liquids. One of the key properties of these materials is semiconduction. Like cell membranes, connective tissues including bone have electrical fields imposed on them.[40] Liquid crystals, then, comprise the bulk of the human body.

When the energy within one of these coherent structural domains reaches a certain threshold, the molecules vibrate in unison: they vibrate coherently and emit light. This light does not stop at the surface of the cell, tissue, or at the surface of the organism. The properties of the light are expected to change when biological activities change. It was predicted that coherent Fröhlich oscillations are information-rich signals that integrate processes such as growth, injury repair, defense, and the coordinated functioning of the organism as a whole. Fröhlich also predicted that these signals have important roles in the regulations that lead to unity of function– wholeness–in the organism. We shall see below that Mae-Wan Ho developed a technology for visually confirming the movements of coherent energy in intact organisms.

In terms of the absorption and circulation of energy within organisms, biological coherence allows for the storage and mobilization of energy that enables the organism to carry out its various functions. Interestingly, the word, crystal, is derived from a Greek word, κρύσταλλο, meaning frozen light.

Biological coherence and the sensitivity of living systems

Finally, quantum coherence has important implications for the question of the sensitivity of living systems to environmental influences, including laser light.

For centuries, naturalists have noticed behavioral changes in plants and animals that correlate with tiny environmental influences such as variations in electrical, magnetic, and electromagnetic fields, including visible and near visible light. In the older literature the observed sensitivities of organisms were reported in an anecdotal fashion, and seemed improbable to many non-biologists. Some well-documented sensitivities are so mind-boggling that scientists tended to dismiss them as artifacts: errors in experimental design or in data analysis. These sensitivities are much less bewildering to the naturalist, who understands that there is a huge evolutionary and survival pressure for sophisticated biosensors that operate at the limits set by physical considerations such as quantum physics. The sensitivities observed by naturalists evolved to enable organisms to find prey, avoid predators, navigate, sense approaching weather patterns, and adjust their activities and metabolism to harmonize with the large rhythms of nature, such as tides and other diurnal influences. In some parts of the world, the behavior of animals is used to predict earthquakes. Understandings of the mechanisms by which biosensors operate have emerged from multi-disciplinary biophysical investigations of which many scientists are simply unaware. Skepticism has given way to acceptance because of careful studies carried out in a variety of species. Credibility has been firmly established by irrefutable data from well-replicated and well-controlled studies. Quantum coherence has provided an important theoretical basis for these sensitivities. The emerging concepts do not require us to abandon our sophisticated understandings of physiology, biochemistry or molecular biology. Instead, they extend our picture of living processes, and of healing, to finer levels of structure and function. Our definition of living matter is being expanded to incorporate the physics and chemistry of solid sate and quantum physics, including semiconduction, quantum mechanics, liquid crystals, and biological coherence.

All who have an interest in energetic therapies such as 3LT™ need to look at the classic 1977 paper of Adey and Bawin on brain interactions with weak electric and magnetic fields, published in the Neurosciences Research Program Bulletin. This paper was instrumental in resolving a long-standing controversy:

> *…a striking range of biological interactions has been described in experiments where control procedures have been adequately considered…The existence of biological effects of very weak electromagnetic fields suggests an extraordinarily efficient mechanism for detecting these fields and discriminating them from much higher levels of noise. The underlying mechanisms must necessarily involve ever increasing numbers of elements in the sensing system, ordered in particular ways to form a cooperative organization and manifesting similar forms and levels of energy over long distances.*
>
> ~Adey & Bawin[41]

The “ever increasing numbers of elements in the sensing system, ordered in particular ways to form a cooperative organization…” refers to the liquid crystalline domains of the body, with their capacity to collapse into Bose-Einstein condensates, as described above. The precise ways quantum coherence gives rise to the profound sensitivities of living systems is a subject for a separate paper.

The discoveries of Gurwitsch and colleagues, the concepts of non-linear dynamics (Prigogine) and quantum coherence (Fröhlich) laid the foundation for the research on biophotons by Fritz-Albert Popp and Mae-Wan Ho, to be described next.

Fritz Albert Popp: biophotons

The modern era of biophoton research, from 1974 onwards, began with the work of Fritz-Albert Popp and his colleagues in Germany.[42] During the past 30 years, Popp and colleagues around the world have demonstrated conclusively that living systems absorb and emit coherent biophotons. There are now about 40 groups, in a dozen or so countries, researching the theory and practical applications of this research, using state of the art techniques. From this research we now know that all organisms, including humans, emit a glow that is too faint to be detected with the eye, but that can be measured precisely with photomultipliers that amplify weak signals millions of times. The intensity of this biophotonic glow is some tens of thousands of photons per square centimeter per second. Bischof calculates that this glow corresponds to the light of a candle seen from a distance of 15 miles. Biophotons range in wavelength from 200 to 800 nanometers, i.e. from the ultraviolet through the visible spectrum to infrared light. These emissions should not be confused with chemical bioluminescence, which is much stronger and has entirely different properties and origins. In contrast to chemical bioluminescence, biophoton emission increases in intensity hundreds or thousands of times before death of cells, and then ceases upon cell death. Injury to cells stimulates the production of biophotons. The coherent biophotonic light is not steady, but changes with any change in the activity of the organism. Biophoton output changes during the cell cycle, and is influenced by any change in the physiological state of the organism.

From the perspective of 3LT™, the most important aspect of biophotons is their coherent nature. The light produced by living systems is highly organized: it is biological laser light.

One of the ways of studying biophoton emission is by “induced emission” in which a short flash of light is introduced into the organism, and the investigator waits for it to be re-emitted. It turns out that the light exhibits an extended decay process lasting from minutes to hours. In his research, Popp has explained how the characteristics of the decay process prove that the light is coherent, and that light is actually stored in the organism.[43] The main storage site appears to be the DNA in the cell nucleus.[44] Moreover, the re-emitted light does not necessarily emerge from the place where it was introduced. These non-local effects lead to the conclusion that the light is not being emitted from isolated DNA molecules. Instead, the DNA molecules throughout the organism are linked together by a system-wide unified and unifying coherent radiation field. This unifying field extends throughout the organism and around it, and is a good candidate for the organizing principle that regulates all of the processes taking place within the body.

Popp has concluded that weak light emissions orchestrate the body, and that photonic communication enables every cell to know what every other cell is doing.

> *It is a holographic field of standing waves which is able, through a broad spectrum of frequencies and polarizations and in close interplay with all material structures, to transmit signals with the speed of light to any place in the organism and to activate or to inhibit biochemical process, to organize matter, and much more.*
>
> ~Bischof, 2005

Guenther Albrecht-Buehler: Cells respond to light

Complementing the research of Gurwitsch as well as Fritz-Albert Popp and colleagues, on biophoton emissions from cells and tissues, is research on the specific ways cells use light to communicate with each other. Guenther Albrecht-Buehler is the Robert Laughlin Rea Professor of Cell and Molecular Biology at the Northwestern University School of Medicine in Chicago. He has done pioneering research on what he calls *Cell Intelligence*.

Cell movement is not random. Instead, cell migrations are purposeful and carefully controlled. The defense of the body from bacteria and other pathogens requires that white blood cells migrate through the walls of blood vessels and into tissues that are compromised by infection. The remarkable process by which cells of the immune system cross capillary walls, called diapedesis, is a crucial step in healing. Cell migration and diapedesis are major topics of modern biomedical research. The same cells that destroy bacteria also remove cellular debris. Finally, various kinds of cells migrate to a site of injury to replace cells that have been killed or damaged. These cell migrations are, in fact, the most important aspect of healing and defense against disease.

In 1991, Albrecht-Buehler reported studies in which he used a special microscope to study the effects of microscopic infrared spot illumination on the migrations of cultured cells. In 25% of the cells he studied, pseudopodia were extended toward the light source. If cells were presented a pair of adjacent light sources, 47% of the cells extended towards them, and in 30% of those examples the cells sent separate pseudopodia towards each light spot. The strongest responses were obtained with light in the range of 800-900 nm pulsed at rates of 30-60 pulses per minute.[45] A dramatic video of the attraction of a cell toward a pulsing light source can be observed on the web.[46]

A possible conclusion from the above study is that cells mistook the red spots for other cells that were emitting red light. To test this possibility, Albrecht-Buehler conducted another study to see if cells could detect each other across a thin layer of glass. One group of cells was densely plated onto one side of a thin glass film and allowed to attach and form their typical patterns. A second batch of cells was then sparsely plated on the opposite face of the glass, and the samples were placed in the dark for 7 hours to allow

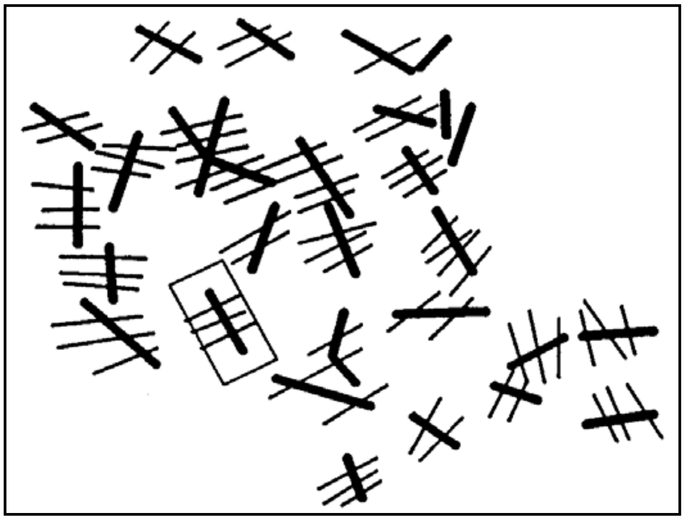

Figure 12.
Orientation of cells on two surfaces of a thin piece of glass. One group of cells was densely plated onto one side of a thin glass film and allowed to attach and form their typical patterns. A second batch of cells was then sparsely plated on the opposite face of the glass, and the samples were placed in the dark for 7 hours to allow the cells to attach and spread. The second batch of cells did not distribute themselves randomly, but were instead oriented at angles with respect to the cells on the opposite face of the glass. From Albrecht-Buehler G, 1991. Rudimentary form of cellular "vision." Proceedings of the National Academy of Sciences, USA 89:8288-8292.

the cells to attach and spread. The second batch of cells did not distribute themselves randomly, but were instead oriented at angles with respect to the cells on the opposite face of the glass.[47] Figure 12 shows the orientation of cells on the two surfaces of the glass.

This is another example of interactions between cell populations that are optically coupled (via a thin layer of glass) but chemically separated so that communications via chemical mediators such as hormones, growth factors and neurotransmitters could be excluded. To be certain that light mediated the interactions across the glass interface, Albrecht-Buehler attempted to repeat the effect with thicker glass and also with thin glass that had been coated with a thin metallic film that would absorb any light signals. In both of these cases, the orientations of the two cell layers were random, indicating that the orienting signals were some form of electromagnetic radiation. To narrow the frequency range of the radiation, additional studies were done with thin silicone films evaporated onto the glass surfaces. These films strongly absorbed light in the blue end of the visible spectrum but became increasingly transparent to red and infrared light. A repeat of the studies with two separate layers of cells showed that the "orienting signals" were present with the silicone coating. This meant that the signals were most likely in the red to infrared range.

When taken with the previous study using infrared light sources, the results pointed to an infrared signaling process between cells. The glass did not allow the penetration of chemical, electrical, electrostatic signals or other kinds of signals.

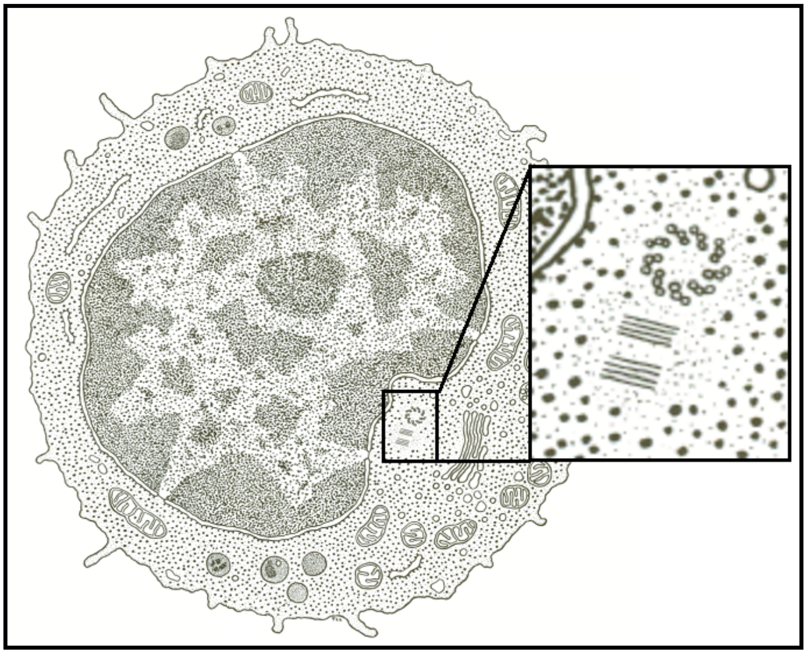

Figure 13.
The centrioles as seen in the electron microscope. From Lentz, TL, 1971. Cell Fine Structure. An atlas of drawings of whole-cell structure. W.B. Saunders Company, Philadelphia. Used by permission of W.B. Saunders Company.

Another study[48] involved irradiating latex beads with infrared light and observing the responses of nearby cells, which were attracted to the light. Some cells were then irradiated with tiny infrared spots that focused on specific parts of the cytoplasm. The responses of cells to the irradiated latex beads were inhibited when the cell center was simultaneously irradiated with a beam of the same kind of light. Irradiating other parts of the cells had no such effect. The results suggest that the cellular infrared detector is located at the cell center. These and other studies supported an earlier proposal that the centrosome, containing the centrioles, is the light sensor in cells.[49] Figure 13 shows the structure of the centrioles.

Albrecht-Buehler concluded that cells have "eyes" that enable them to "see", i.e. they can map the directions of near-infrared light sources in their environment and steer their movements with respect to those light sources. The larger the amount of light that is being scattered from cells in a particular part of the organism, the greater the distance from which other cells will come together and aggregate. Cellular "vision" involves sophisticated "eyes" that are present within every cell. Albrecht-Buehler concluded that these eyes are linked via cytoplasmic "nerves" (microtubules) to a sophisticated signal processing system, or the "brain" of the cell, that is, in turn, linked to the movement control system of the cell.

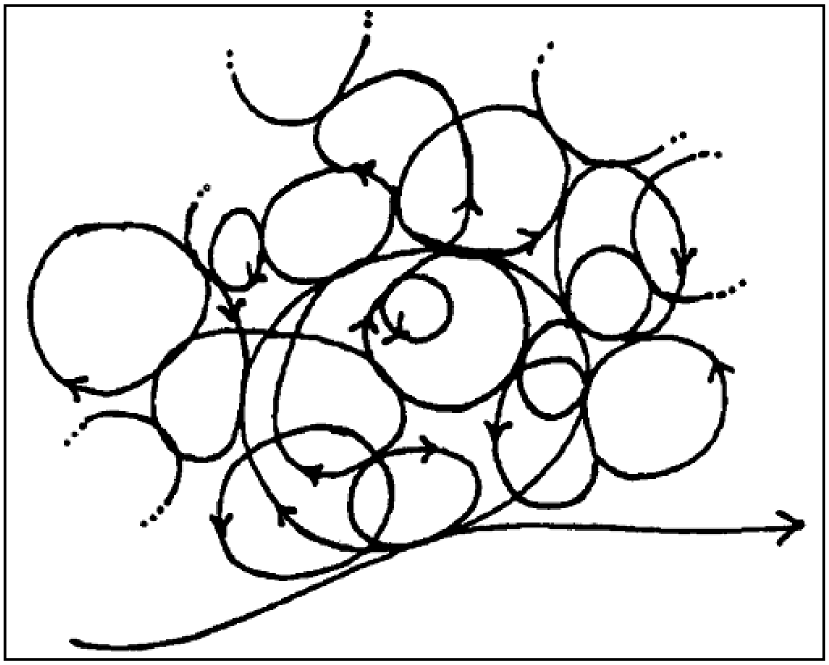

Figure 14.
The many-fold cycles of life coupled to energy and information flows. Organisms can take advantage of a complete spectrum of coupled cycles, storing and mobilizing energy and information using many different kinds of efficient transfers. Energy and information input into any of the body's systems can be readily delocalized over all systems; conversely, energy and information from all systems can become concentrated into any single system. Energy coupling in living systems is symmetrical, which is why we can have energy at will, whenever and wherever required. From Ho, M-W, 1996. The biology of free will. Journal of Consciousness Studies 3:231-244.

Albrecht-Buehler's more recent studies have explored the distances involved in cell-cell communication via infrared light. The maximum distance was related to the distance light travels before it is significantly diminished by scattering.

It is fascinating that Albrecht-Buehler did not cite the earlier work of Gurwitsch, who also narrowed the cell to cell communication in root cells to light signals, and who also found that cells respond more to pulsing than to steady light sources.

Albrecht-Buehler's research has identified the eyes and nerves of the cell and the ways they link to the cellular "brain" and movement apparatus. A recent report suggests that neurons are ideally designed to communicate via light.[50]

Mae-Wan Ho: visualizing coherence

As a colleague of both Herbert Fröhlich and Fritz Albert Popp, Mae-Wan Ho has pioneered research in several important aspects of biological coherence.[51] Her work has already been mentioned here several times.

Ho and colleagues developed a polarizing microscope that permits visualization the coherent domains (liquid crystals) in growing organisms.[52] The apparatus involves polarization optics that take advantage of the structurally coherent arrangements of molecules. As organisms develop and function, their liquid crystalline domains undergo dynamic transitions that can be seen as colored interference patterns. Brilliant interference colors are generated, specific for each tissue. The colors arise from the birefringence of the molecular arrays. Birefringent materials are substances that have a different index of refraction depending on the orientation of the light passing through them. The apparatus developed by Ho and colleagues enables us to see quantum coherence in action.

Perhaps Ho's most important role has been the development of a whole-systems perspective that can account for the way organisms have energy at will, whenever and wherever required, in a perfectly coordinated way. Coordination implies communication, and the whole process involves exquisite sensitivity to the environment as well as conscious control. Ho has summarized the *metabolic net*, the many-fold cycles of life coupled to energy and information flows (Figure 14). Organisms can take advantage of a complete spectrum of coupled cycles, storing and mobilizing energy and information using many different kinds of efficient and noiseless transfers. Energy and information input into any of the body's systems can be readily delocalized over all systems; conversely, energy and information from all systems can become concentrated into any single system. Again, energy coupling in living systems enables us to have energy at will, whenever and wherever required. Ho refers to the individual freedom of parts, documented by Bohm and colleagues, as a *molecular democracy* of distributed control:

> *Thus, the essence of the organic whole is that it is distributed throughout its constituent parts, with no center of control, no governors, no hierarchical levels or line-managers or regulators processing information down the line of command. Instead, pervasive, moment to moment intercommunication throughout the system renders part and whole, local and global completely indistinguishable. Each part is as much in control as it is sensitive and responsive…It is, in effect a vast array of Fröhlich systems all coupled together.*
>
> ~Mae-Wan Ho[53]

Conclusions

This survey of the literature in the fields of biophysics, cell biology, quantum physics, and biophotonics enables us to look at nearly a century of careful and groundbreaking research on the biology of light. Tying this work together leads to some specific conclusions:

- Living cells, tissues and entire organisms emit light in the spectral range from infrared to visible to ultraviolet.

- Some of these light emissions consist of coherent biophotons; some are not coherent.
- Coherent biophotons are produced by cooperative molecular vibrations taking place in highly ordered arrays found in DNA, the cytoskeleton, cell membranes, and extracellular connective tissues, including bone.
- Quantum physics predicts that the behavior of highly coherent molecular domains can be described as Bose-Einstein condensates. This is a state of matter that has been well characterized for inorganic systems such as liquid helium and lasers.
- These coherent domains have key roles in the absorption, storage, and mobilization of energy within the organism.
- Biological coherence also explains the extreme sensitivity of living systems to tiny signals in the environment.
- Cells are responsive to very low levels of light, particularly if the light is pulsed on and off.
- Even a single photon can produce a cascade of effects on a population of cells or tissues by a process known as a high-speed branched-chain process or *avalanche effect.*
- Several mechanisms explain how a single photon can produce a large scale change in an organism. One is the avalanche effect, another is quantum coherence. Light and energized electrons can be delocalized: they can migrate from one domain of the body to another rapidly and noiselessly and without loss as *wavefunctions* rather than as particles.
- Another possible mechanism is a direct cell to cell transfer. For example, it has been discovered that the fibroblasts in the skin contact each other to form a body-wide network.[54] If it were demonstrated that photonic communication can take place through this reticular web, it would mean that projecting laser light on one part of the skin would affect the entire skin.
- Cells respond to light in predictable ways:
    - By dividing
    - By migrating
    - By altering their metabolism

On the basis of these discoveries, it is possible to put forward a logical and testable hypothesis: Injury brings about damage and destruction of cells; damaged cells produce more light than normal cells, and this light travels throughout the organism, signaling other cells and attracting them to the site of injury. Some of these cells clean up damaged cells and destroy bacteria. Others, such as fibroblasts, divide to provide replacements for cells that have been lost. One of the therapeutic effects of laser light is to artificially simulate the cell-cell communications and trigger cell migration and cell division. Laser light can have a protective function by *simulating* the photonic aspects of an injury without actually damaging tissues. The flow of energy through a system organizes the system, so laser light may open up and facilitate the operation of biophotonic communication pathways. Disturbed tissues will scatter light and inhibit the flows of photonic energy and information needed for injury repair. Such disturbances include:

- Scars
- Reduced circulation
- Tight muscles
- Reduced range of motion
- Inflammation
- Bruises
- Broken bones
- Injured or damaged tissues
- Denervation

Quantum coherence gives rise to a highly mobile form of energy and information that can be transferred from place to place with great speed and efficiency and virtually no loss. In terms of physics, the energy is *delocalized*.

An important challenge is for researchers to appreciate the significance of quantum coherence in living systems so we can understand in more detail how coherent light affects physiological processes and regulations.

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