Synopsis:
In order for life scientists to better understand the relationships between cells of living organisms and electromagnetic radiation, this introductory chapter gives some explanations about general concepts in electrodynamics. These notions encompass the physical nature of electromagnetic energy (electric and magnetic fields), its origin and its different forms and characteristics (fields, waves, photons of different frequencies) including also modalities how to generate or pick up this energy via antennas or photonic detectors – with the latter being useful for detecting biophotonic emissions of cells. The concepts of resonance and coherence are also explained, as well as how electromagnetic radiation interacts with matter. All this issues constitute the minimum “tools” required for entering into the fascinating area exploring the interplay between fields and living cells. It serves to grasp the knowledge and information exposed in the other chapters of this book.
It is the aim of this chapter to present basic physical concepts for a better understanding of electromagnetic fields, and especially the concept of photons along with crucial properties, such as coherence. Since living organisms emit photons both within cells but also outside the body, it is assumed that biophotons play a crucial role in inter- and intra-cellular communication and in the organization of a living system. Such ultra-weak photon emission can be measured with devices such as photomultipliers. This type of instrumentation has shown to be a reliable tool for diagnostic purposes within the field of biophotonics. Yet further research efforts and improved detector efficiencies are urgently required. Further improvement of this technology, for example regard enhancing photonic yield and signal to noise ratio. The emerging 2nd-generation detectors will enable exploration of biophotonic properties in living organisms even beyond existing limitations. This will both include measurements of the spectral intensities of biophotons emission as well as the biophotonic dynamics within cells there is no generally accepted evidence for physical coherence of biophotons
The electromagnetic spectrum contains a wide range of different wavelengths, each of which exhibits different characteristics. It is divided into various domains that are named according to their dominant mode of application. Beginning with the most energetic spectral segment – one can find among others γ-radiation and X-rays (ionizing radiation) and less energetic radiation (non-ionizing), with the threshold within the ultraviolet (UV) band. The latter covers a spectrum of roughly 10 to 390 nm .... Light waves (VIS) in the range of 390 to 780 nm code for the visible color-spectrum .... Near infrared radiation (IR) greater than 780 nm all the way down to 1 mm is most often related to thermal radiation .... Then there is far-IR, or microwaves from 1 mm to 30 cm wavelengths .... Radio waves cover a wavelength range of 30 cm to several km .... All wavelength segments mentioned so far seem to differ from each other, yet still all belong to the single electromagnetic spectrum, which is commonly referred to as the spectrum of electromagnetic radiation (EMR). The only thing that is really different from one wave to another is frequency of oscillation.

Fields (1/6)

.... like poles repel, opposite poles attract ....

EF: the electric force per unit charge
MF: the magnetic force per unit dipole
or, the force of a moving charge (EF)

.... both EF & MF are storehouses of energy!

Figure 2 a-b: Electrostatic field created by stationary positive and negative charges (left pane). Magnetostatic field created by a magnet’s N- and S-poles (right pane).

ad a) Lines of force for a pair of equal but opposite charges. Note that the lines emanate from the positive charge and terminate on the negative charge.

ad b) Interestingly, the magnetic field lines continue inside the magnet and form closed loops. The source of the field is the motion of electrons in the iron atoms that compose the magnet.

Figure 5: Schematic of a stepwise unfolding dipole LC-antenna circuit revealing the concept of the electric (voltage, V) and the magnetic (current, I) field lines (EMF, electro-magnetic field; B, magnetic field component of EMF related to the current; E, electric field component of EMF related to the voltage. The geometric dimensions of the oscillator are related to the electric properties of inductance L and capacitance C.[1]

"Let there be electricity and magnetism, and there is light"

Maxwell, 1860

The vibrating EF & MF regenerate each other; i.e. the amalgamation of electricity, magnetism, and light - as different aspects of the same thing – constitute the electromagnetic field.

Perhaps the most dramatic moment in the development of physics during the 19th century occurred to J.C. Maxwell one day in the 1860's, when he combined the laws of electricity and magnetism with the laws of the behavior of light. As a result, the properties of light were partly unravelled — that old and subtle stuff that is so important and mysterious that it was felt necessary to arrange a special creation for it when writing Genesis. Maxwell could say, when he was finished with his discovery, "Let there be electricity and magnetism, and there is light!"[1]

Figure 3: Plane electromagnetic wave vibrating with its vectorial fields in sinusoidal manner as produced by discharging sparks or oscillating molecules; B, magnetic field vector; E, electric field vector; k vector of propagation denoted by the circle and the central dot (that is: pointing towards the reader).[2]


http://upload.wikimedia.org/wikipedia/commons/3/35/Onde_electromagnetique.svg
Figure 7: Waves shown at a given time and as a function of distance: a) Polychromatic, incoherent light comprising several wavelengths; b) monochromatic light composed of waves in random phase: temporally coherent but spatially incoherent; c) laser light: spatially and temporally coherent.

Nature presents us a deep riddle that compels us to accommodate seemingly polar opposites (determinism and probabilities at the same time). What nature is telling us is that coherence does not mean uniformity. You can begin to understand it by thinking of an orchestra .... Where everyone is doing his or her own thing, as yet keeping perfectly in tune or in step with the whole. Imagine a huge superorchestra playing with instruments spanning an incredible spectrum of sizes from a piccolo of 1nm up to a bassoon or bas viol of 1m or more, and a musical range of 72 octaves. The amazing thing is that this superorchestra never ceases to play out our individual songlines, with a certain recurring rhythm and beat, but in endless variations that never repeat exactly. Each and every player, however small, can enjoy maximum freedom of expression, improvising from moment to moment, while maintaining in step and in tune with the whole. However, imagine if some members of the orchestra play the wrong tune (are incoherent), it disturbs the entire harmony of the explicate order.

The theory of quantum coherence (superposition of wave functions that collapse once interacting with the environment) does not require the existence of a single mode, or frequency, of light. There can be many modes, so long as they are coupled. Nor does it require the existence of high intensities of light. The factorizibility of coherent states has been experimentally verified, and high degrees of coherence (>6 orders have also been measured in commercial lasers). The theory of quantum coherence does not require the existence of a single mode, or frequency, of light. Coherence does not require the existence of a single frequency; it is only necessary for the different frequencies to be coupled together so as to represent effectively a single degree of freedom. Hence, there can be a broad band of frequencies coupled together or intercommunicating, so that energy fed into any frequency can be propagated to all other frequencies – exactly that happens in living systems.

Source: Ho MW 2003; The Rainbow and the Worm - The Physics of Organism; World Scientific, Singapore
Double-Slit Experiment:

Breaking a single wave-front into two coherent portions ....

.... yields a pattern with constructive and destructive interference.

Figure 8: Double-slit experiment: The wave front generated at the source targets the openings (slits) at the barrier. As both resulting cylinder-waves originate at the same source, they are coherent to each other. Constructive and destructive interference can be seen at the screen as alternating intensity patterns.[1]

Based on their undulating properties, waves can interfere with each other; i.e. they can add up together (constructive interference), or subtract (destructive interference). Interference between two waves is all the more significant as the waves are coherent, either because their frequency is the same or because they come from the same source.

Regarding light, the double-slit experiment nicely illustrates interference: a coherent light source illuminates a plate pierced by two parallel slits; the light passing through the slits is observed on a screen placed behind this plate, as shown in the figure. One obtains a diffraction pattern: destructive interference will correspond to dark bands on the screen, while constructive interference will correspond to bright bands. If these waves produce a “less-than-perfect” interference pattern then these are said to be partially coherent.

Harmonic Oscillation (1/3)

Mechanical Resonance ….

Pumping a swing in rhythm with its natural frequency yields a large amplitude.

…. and Damping

Loss of energy due to friction.

\[ Q\text{-factor} = \frac{f_0}{\Delta f} \]

Figure 6: The swing with equilibrium point (EP), where the kinetic energy \( E_{\text{kin}} \) is maximum and the potential energy \( E_{\text{pot}} \) attains its minimum value. The opposite is the case at the turning point (TP) where \( E_{\text{pot}} \) reaches its maximum and \( E_{\text{kin}} \) its minimal value. The right part of the image depicts the Q-factor in which the oscillating system is subject to a stimulating frequency. At resonance, the oscillating system attains its maximum value. The less damping; the sharper the resonance peak.\[1\]

When the frequency of a forced vibration on an object matches the object’s natural frequency, a dramatic increase in amplitude occurs = resonance (lit. resounding or sounding again).

**Q-factor** or quality factor: It characterizes resonator performance and is the ratio of stored energy divided by the average energy dissipated per cycle of resonance.  

i) a low Q-factor denotes a damped oscillation that loses a lot of the resonating energy thereby causing the resonating effect quickly to fade out towards zero.

i) a high Q-factor on the other hand, denotes an undamped resonator with almost no loss of the stored energy, and as such is able to resonate for quite a long time even without periodic strokes of a synchronized time base that is coupled to the natural resonance frequency of the oscillating system (see Fig).

The Q-factor is a direct measure of the sharpness of resonance, one can say that low-Q resonators (broad) are found in wide band applications, whereas high-Q-resonators (sharp) are so specific that these resonate tightly around a specific frequency

Image: \[1\] inspired by Q-factor (accessed 25th April, 2012):  
Harmonic Oscillation (2/3)

Up- / Down-scaling Resonance

… moving charges are found in each major domain ….

Figure 4: Moving charges – from galactic dimensions all the way down to atomic dimensions. While charges on the astronomical scale are easier to imagine (e.g. the constant exposure of solar wind on the rotating earth), or on the atomic scale (quantum jumps of electrons), moving charges on cellular level are more peculiar, as these depend more on the electron charge distribution of the affected molecular structures.
Harmonic Oscillation (3/3)

The LC-unit as an electronic equivalent

Wikipedia, 2012

Figure 5: Formation of a dipole out of a LC-resonator circuit.[1]

Animation of a half-wave dipole antenna transmitting radio waves, showing the electric field lines. The antenna in the center is two vertical metal rods, with an alternating current applied at its center from a radio transmitter (not shown). The voltage charges the two sides of the antenna alternately positive (+) and negative (−). Loops of electric field (black lines) leave the antenna and travel away at the speed of light; these are the radio waves.[2]

Animated diagram of a half-wave dipole antenna receiving energy from a radio wave. The antenna consists of two metal rods connected to a receiver $R$. The electric field ($E$, green arrows) of the incoming wave pushes the electrons in the rods back and forth, charging the ends alternately positive (+) and negative (−). Since the length of the antenna is one half the wavelength of the wave, the oscillating field induces standing waves of voltage ($V$, represented by red band) and current in the rods. The oscillating currents (black arrows) flow down the transmission line and through the receiver (represented by the resistance $R$).[2]

https://en.wikipedia.org/wiki/Antenna_(radio)
Figure 6: Formation of coherence domains (CDs) of aerosolized water molecules. The free-floating dipoles start to feel mutually attracted and establish coherent resonance clusters that result in the formation of 75 nm large CDs in which molecules resonate in unison. The newly formed coherent polarizing field becomes entrapped by CDs themselves and reveals a characteristic wavelength of about 100 nm. The formation of CDs is a fundamental property of liquid water and unlike the laser, no energy pumping is required to establish coherence (Arani et al, 1995).

Source: Chaplin M., 2007; http://www.lsbu.ac.uk/water/index2.html
Figure 11: The electromagnetic nature of matter and their discrete excitation patterns (shown on the left half of the image), with the upper part highlighting a 1D sketch of the inter-atomic energy requirements to induce excitation until ionization is reached, whereas the lower part reveals the excitable orbits of the atom in 3D. The right half of the image highlights the various modes of interaction: (a) if the ingoing photonic energy is too small or the wavelength large in comparison to the atom, the target remains in its ground state; the outgoing photon is scattered but maintains its energy; (b) with a more energetic photon the interaction with the atom results in an exited state and the release of a somewhat less energetic photon; (c) if the energy of the incident photon matches with that of the energy difference to achieve transition into the excited state, relaxation eventually brings the atom back to the ground state and yields a photon identical to the incident one; (d) the excitation energy is high enough to lift the atom in a very excited state; relaxation occurs in steps producing less energetic photons until the atom is completely de-excited; (e) the energy of the incident photon causes ionization of the atom; (f) here the photon induces both ionization and a less energetic photon is released; (g) an already excited atom when hit by an incident photon results in relaxation of the atom whereby a photon is released that is coherent to the incident photon (e.g. laser light [1]) – modified after Tippler, 1990.

http://micro.magnet.fsu.edu/primer/lightandcolor/lasersintro.html
**Matter-Wave Interaction (3/5)**

Matter as a transducer:
Propagating EMF in water ….

…. a swinging pendulum between excitation and relaxation ….

…. speed of propagation
\[ c_{\text{H}_2\text{O}} < c_{\text{vacuum}} \]

Figure 11: A light wave incident upon a body of water sets up vibrations in the water molecules that produce a chain of absorptions and re-emissions. Because of the time delay between excitation and relaxation (in-between molecules it still travels with “c”) light travels more slowly in water (modified after Hecht, 1993).[1]


Figure 12: Another example regards a camp-fire. It emits a huge amount of radiation – some VIS but most of it in the IR. Sitting in front of it, one has the sensation that it literally burns the skin, yet measuring the temperature of the air in front of that person (depending on the detector used) does not correspond to the perceived sensation of heat. The skin feels “hotter,” than the air in front of it. Rather than heat, it’s the charges in the skin-receptors that are bouncing more vigorously (see resonance and Q-factor), thus suggesting an excess influx of thermal energy. Seen with an IR-camera, brightness and darkness of a fire does not necessarily imply higher or lower temperature; it merely reflects the intensity of moving charges.

Image: False color thermogram of a recently used car revealing the IR by the object in proportion to its temperature. The hottest parts of this image are the bonnet (heated by the engine), the wheels (warmed by the brake discs) and the front of the interior (Geoff, 2xxx).[1]

Matter-Wave Interaction (5/5)

Matter as a transducer:
Incident EMR \( E_{\text{IN}} = h \cdot \nu_{\text{UVIS}} \) vs Exitent EMR \( E_{\text{EX}} = h \cdot \nu_{\text{IR}} \)

A question of ORDER (Entropy)

modified after Lutgens & Tarbuk, 1998

Figure 13: Since the atmosphere possesses radiation windows, UV-VIS hits planet earth (@ shorter \( \lambda \)), while IR radiates back into space (@ longer \( \lambda \)). Energetically, UV-VIS-quanta are higher than those of IR-quanta. Hence, more quanta need to be re-radiated back into space, thus lowering entropy on earth.

The increasing disorder (entropy or the energy converted into heat) created in this process eventually radiates back into space as microwave (IR) radiation. In order to meet the energetic balance, the reemitted amount of microwave energy should match with the incident radiation provided in the form of sunlight. The vital difference however resides in the fact that sunlight has a shorter wavelength than the microwaves re-emitted from earth. Since, quantum mechanics tells us that all radiation appears also in the form of quanta, UV-VIS quanta contain more energy than IR-quanta. Our planet gives off more quanta than it receives from the sun ..... In a particle analogy, this implies that in a system containing more particles, this system has more degrees of freedoms than one containing fewer particles. The entropy of the biosphere is kept low by dissipating excess entropy, Our planet is a net exporter of disorder - of entropy (Norretranders, 1998).

Cavity Resonator

Wavelengths for which the distance between two opposite walls is a multiple of half the wavelength ($L = N \cdot \frac{\lambda}{2}$)

$A_{cell} \approx 0.019 \text{cm}^2$

... Area of "solar" coherence

Figure 14a: Example of parallelepipedic cavity resonator. A map of the electric field is displayed for one particular mode of resonance, at a specific frequency (Egot, 2001)[1].

Figure. 14b: A biological cell seen as a cavity resonator for electromagnetic waves (modified after Popp, 1984 in Rothe 2006) [2].

According to the Cittert-Zernike theorem, solar radiation is coherent within an area of 0.019 cm$^2$ – a dimension that nicely correlates with the area of biological cells. This implies that energy within this range - rather than being converted to heat - is used for building and maintaining living structures.[4]

The phenomenon of interference applied to coherent waves travelling in opposite directions gives rise to stationary waves, also called standing waves. A pure standing wave does not propagate. The nodes and antinodes of these waves remain at the same locations over time. One way of creating a standing wave is to use a material, which reflects an electromagnetic wave, called an incident wave. This material (such as a metallic conductor) will impose conditions on its surface exposed to the incident wave: these conditions on the electromagnetic field are termed boundary conditions. They will determine the origin of the reflected wave and the wave resulting from the superposition of the incident and reflected waves will be a standing wave.

In terms of wavelength, the incoming EMR regarded as an harmonic of the ground oscillatory mode (here the dimensions of the cell) yielding the standing wave pattern, the perpendicularly oriented phonon-wave pattern represents the oscillatory mode of the associated heat transfer among molecular structures within the cytoplasm and the nucleus.

**Phonons:** In physics, a phonon is a collective excitation in a periodic, elastic arrangement of atoms or molecules in condensed matter, such as solids and some liquids. Often referred to as a quasiparticle,[3] it represents an excited state in the quantum mechanical quantization of the modes of vibrations of elastic structures of interacting particles. In practical terms, the atoms in a crystal are neatly arranged in a uniform, repeating structure; when heated, the atoms can oscillate at specific frequencies. So, the bonds between the individual atoms in a crystal behave essentially like springs. When one of the atoms gets pushed or pulled, it sets off a wave (or phonon) travelling through the crystal, just as sitting down on one edge of a trampoline can set off vibrations through the entire surface.


Figure 15: With the discovery of fractal antenna design their geometries could be downscaled to such an extent that these are now incorporated into the circuit-board (Hohlfeld & Cohen, 1999). Apart from the usual phone-characteristics, modern mobile communication devices also offer features, like Bluetooth, Wi-Fi, and other wireless services each using separate frequencies. In order not to rely on an additional set of stubby antennas sticking out of the handset, a single fractal antenna is used instead. A fractal antenna is self-similar and as such physically short but electrically long; that is, it is easy to attain regimes where a small antenna has more than one current maximum. Using a fractal design not only makes antennas smaller, but also enables reception of a much wider range of frequencies (Image).

The concept of a fractal design applied to antennas is very similar to molecule spectroscopy. In fact UV-, VIS-, and IR as well as Raman spectroscopy utilizes absorption of EMR in electronic bands of molecular species— a well established technological feature enabling identification of beta-sheet and alpha-helix folding patterns in proteins (Greenfield & Fasman, 1969). Here, photonic absorption is a function of bond energy of the absorbing electrons involved and as such provides a fingerprint-spectra that is unique to a given molecule. In similar way one can envision broad-band EMR-coupling among biomolecules due to fractal properties as not so far fetched. Such coupling could easily be envisioned as a contributing factor to up- or downregulate metabolic feedback loops – be it for beneficial or adverse purposes.

Image: Concept of a fractal wide-band planar antenna: Increasing iterations of the loop are reflected by an increase in the modes of resonance. The more iterated, the more complex its shape and the more absorption windows around the center-frequency become available (Cohen, 2005).

Figure 16: Several immunoglobulin domains make up the two heavy chains of the antibody. Schematic on the left, folded protein on the bottom right; LC-equivalent at the top right.[1]

Figure 17a: A helical antenna is an antenna consisting of a conducting wire wound in the form of a helix. In most cases, helical antennas are mounted over a ground plane. The feed line is connected between the bottom of the helix and the ground plane. Helical antennas can operate in one of two principal modes — normal mode or axial mode.

In the normal mode or broadside helical antenna, the dimensions of the helix (the diameter and the pitch) are small compared with the wavelength. The antenna acts similarly to an electrically short dipole or monopole, and the radiation pattern, similar to these antennas is omni-directional, with maximum radiation at right angles to the helix axis. The radiation is linearly polarised parallel to the helix axis. These are used for compact antennas for portable and mobile two-way radios, and for UHF television broadcasting antennas.

In the axial mode or end-fire helical antenna, the dimensions of the helix are comparable to a wavelength. The antenna functions as a directional antenna radiating a beam off the ends of the helix, along the antenna's axis. It radiates circularly polarised radio waves. These are used for satellite communication.

Figure 17b: Deoxyribonucleic acid (DNA) is a molecule that carries the genetic instructions used in the growth, development, functioning and reproduction of all known living organisms and many viruses. DNA and RNA are nucleic acids; alongside proteins, lipids and complex carbohydrates (polysaccharides), they are one of the four major types of macromolecules that are essential for all known forms of life. Most DNA molecules consist of two biopolymer strands coiled around each other to form a double helix.

Figure 18: In recent years, terahertz radiation sources are increasingly being exploited in military and civil applications. However, only a few studies have so far been conducted to examine the biological effects associated with terahertz radiation. In this study, we evaluated the cellular response of mesenchymal mouse stem cells exposed to THz radiation. We apply low-power radiation from both a pulsed broad-band (centered at 10 THz) source and from a CW laser (2.52 THz) source. Modeling, empirical characterization, and monitoring techniques were applied to minimize the impact of radiation-induced increases in temperature. qRT-PCR was used to evaluate changes in the transcriptional activity of selected hyperthermic genes. We found that temperature increases were minimal, and that the differential expression of the investigated heat shock proteins (HSP105, HSP90, and CPR) was unaffected, while the expression of certain other genes (Adiponectin, GLUT4, and PPARG) showed clear effects of the THz irradiation after prolonged, broad-band exposure.

**EMF-antenna (5/6)**

**Figure 19: Epigenetics**: It is the study of reversible heritable changes in gene function that occur without a change in the sequence of nuclear DNA. It is also the study of the processes involved in the unfolding development of an organism. In both cases, the object of study includes how gene regulatory information that is not expressed in DNA sequences is transmitted from one generation (of cells or organisms) to the next - that is 'in addition to' the genetic information encoded in the DNA.

Waddington's "Epigenetic Landscape":

- **Vertical axis**: the distribution is shown in the vertical direction; we have the points on the orbit for a certain value of \( x \). This orbit is chaotic, but if we look at the distribution, it is definitively not fractal. It approximately looks like a U-shaped pattern (higher probabilities at the edges, lower at the center).
- **Depth axis**: the path followed by the ball, as it rolls down, corresponds to the developmental history of a particular organ. There is first an alternative, towards the right or the left. Along the former path, a second alternative is offered; however, it can only be reached over a threshold.
- **Bottom**: interacting network of signal transduction pathways. The pegs in the ground represent genes; the strings leading from them represent the pathways initiated by gene expression. The slope of the epigenetic landscape is controlled by the pull of these numerous pathways which are ultimately anchored to the genes.

**Bifurcation Pattern**: In case of brief disturbances, homeostasis is restored sooner or later as the disturbance passes. On the other hand, if the disturbance or is significantly long, a series of irreversible events bring the organism to a new ‘steady state’. Chronic disturbances favour development or differentiation of “new” tissues (cancer as a result of prolonged and repetitive events of distress?). The **tumour cell as such does not exist** (the bad cell; the bad virus = HN15N, the bad bacteria = *Mycobacterium tuberculosis*, the bad plant = *Caulerpa taxifolia*, the bad animal = *Canis lupus*, the bad individual = *Homo sapiens sapiens*, the bad group of people = Bush’s axis of evil, etc.). It **just depends on the interaction with its surroundings** (the relation is much more important than the entities themselves). Here the disease itself becomes a messenger, the vehicle that tries to communicate to the outside world / brain (i.e. to the westener that sees the body as something separate from the mind).

- Accordingly, the segmental structure of the fruitfly *Drosophila* is not predetermined (preformed) in the egg, but evolves rather from a step-by-step (epigenetic) process that controls the spatial distribution of regulatory proteins that in turn de/activate the corresponding genes sequences – a result of the MGF.
EMF-antenna (6/6)

Biological Resonators
e.g. Epigenome

Figure 20: The transducing effects of aqueous systems when exposed to EMR. Only a fraction of the potential energy delivered by EMR to an aqueous is available to do work. The huge bulk of absorbed energy is re-emitted – particularly as infrared radiation (refer to text for further explanation). In this regard, food likewise contributes to increased ordering but at the same time provides the material precursors needed for biomolecular synthesis.

Water - in particular, organismic water - is an energy transducer for the following pathways.

**Optical**: water samples that are stored in dark-rooms absorb and store IR or microwave radiation (Ovchinnikova & Pollack, 2009b), which becomes re-emitted as visible light that can be detected by PMTs. Exposure of saltwater to radio-frequency leads to the emission of visible light and heat and creates the impression of burning water (NGN, 2007).

**Physico-chemical**: Absorption of IR using a suspension of microspheres in a beaker of water for several hours not only yields a uniformly cloudy suspension but also leads to phase-separation. Directed migration of this particle-free zone can be augmented by unilaterally shining light on it (Ovchinnikova & Pollack, 2009a, Chai et al., 2009). Is of vital importance for metabolic activity for shifting gradients of dissolved molecular species.

**Electrical**: A hydrophilic membrane in a water-bath forms an exclusion zone, which is dominated by an excess of negative charges (Guckenberger et al., 2004). By shining extra light onto the membrane, the width of the zone, and thus its charge accumulation can be increased further (Ovchinnikova & Pollack, 2009b). EZs become automatically established, thereby providing energy to the cell.

**Mechanical**: Immerging a hydrophilic membrane arranged in tubular form into water reveals a directed spontaneous flow through the tube (O’Rourke et al., 2011). Light augments this effect. Essential for water transport from root to canopy via xylem – see redwoods that can grow up to 100 m in height (Pollack, 2001).


**Biological water (2/5)**

Cold light source

**EMF-interaction with biological systems**

- **i) Optical**
- **i) Physico-Chemical**
- **i) Electrical**
- **i) Mechanical**

Shine light on one side of the beaker .... particles start to aggregate leaving a particle-free zone

Beaker with microsphere suspension / Frames taken every 150 secs

**Figure 21a:** Optical: water samples that are stored in dark-rooms absorb and store IR or microwave radiation (Ochinnikova & Pollack, 2009a), which becomes re-emitted as visible light that can be detected by PMTs. Exposure of saltwater to radio-frequency leads to the emission of visible light and heat and creates the impression of burning water (NGN, 2007).

**Figure 21b:** Cylinder-formation dynamics, as observed from above the beaker. Frames were taken every 150 s. Only frames around the critical time are shown. Frame numbers are indicated on each panel.


Figure 22a: **Physico-chemical**: Absorption of IR using a suspension of microspheres in a beaker of water for several hours not only yields a uniformly cloudy suspension but also leads to phase-separation. Directed migration of this particle-free zone can be augmented by unilaterally shining light on it (Ovchinnikova & Pollack, 2009a, Chai et al., 2009). Is of vital importance for metabolic activity for shifting gradients of dissolved molecular species.

Figure 22b: **Inlet**: Water-pH dynamics during charging, recorded from above the chamber. Electrodes situated along the top and bottom of each panel. Times after current-flow initiation are indicated below. The colors of the indicator correspond to the following values of pH: green pH 7, orange pH 4, dark violet pH \(\sim 10\) (Ovchinnikova & Pollack, 2009a).


Figure 23: **Electrical**: A hydrophilic membrane in a water-bath forms an exclusion zone, which is dominated by an excess of negative charges (Guckenberger et al., 2004). By shining extra light onto the membrane, the width of the zone, and thus its charge accumulation can be increased further (Ovchinnikova & Pollack, 2009b). EZs become automatically established, thereby providing energy to the cell.

**Biology** water (5/5)

EMF-interaction with biological systems

i) Optical
i) Physico-Chemical
i) Electrical
i) **Mechanical**

Shine light on one side and the particles start to Flow through the tube ….

Figure 24: **Mechanical**: Immerging a hydrophilic membrane arranged in tubular form into water reveals a directed spontaneous flow through the tube (O’Rouke et al., 2011). Light augments this effect. Essential for water transport from root to canopy via xylem – see redwoods that can grow up to 100 m in height (Pollack, 2001)


Figure 25: **What are Biophotons (BP):** are a general phenomenon of living systems. Practically all organisms emit light at a steady rate from a few photons per cell per day to several hundred photons per organisms per second. It concerns low luminescence from a few up to some hundred photons per second, per cm² surface area, at least within the spectral region from 200 to 800 nm. However, they are the result of energy-matter interaction; i.e.: absorbed electromagnetic radiation (EMR) results in an excited atomic state (quantum jump), while de-excitation emits slightly less EMR. In order to establish trans-molecular communication, all the molecules involved must be in some kind of an excited state (easily achieved since biota operate usually at approx. 300K).

**Purpose of BP:** strongly correlated with the cell cycle and other functional states of cells and organisms, and responds to many external stimuli of stresses.

**Measurement of BP:** based on (i) counting single photons, (i) uses the photoelectric effect, (i) employs a photomultiplier as a detecting device.

**Properties of BP:**[1] 
- high energy per photon compared with thermal or regular chemical activation energies values range: 1.67 – 3.41 eV; $E = h \cdot \nu = h \cdot c / \lambda$ (e.g. green light: $\lambda = 500$ nm & $E = 2.47$ eV/photon); Infrared radiation at its maximum of emission at body temperature (9350 nm) has $~E = 0.132$ eV/photon. The thermal energy $E = K \cdot T$, at body temperature 310K (37ºC) yields 0.61 kCal/mol or 0.027 eV per molecule.
- low Intensity, not visible but much higher than the statistical Boltzmann distribution BP-values $~10^{-1} \cdot E^4$ photons·s⁻¹·cm⁻².
- threshold for human vision $~1 \cdot E^6$ s⁻¹·cm⁻² → bioluminescence is not normally visible → special setups for detection: dark rooms and photon counting devices.
- BP-emission is $1 \cdot E^{10}$ higher than the statistical Boltzmann distribution → the sources are not statistical, thermal equilibrium phenomena.

Source: http://www.tohtech.ac.jp/~elecs/ca/kobayashilab_hp/BiophotonE.html
**What to look for (1/2)**

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<tr>
<th>Quantum flux</th>
<th>Lipid peroxidation</th>
<th>Star light</th>
<th>Moon light</th>
<th>Firefly</th>
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<td>(photon cm⁻² s⁻¹)</td>
<td>Body fluids</td>
<td>Body organs</td>
<td>Level of luminescence - a comparison</td>
<td>Human visual range</td>
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<td>10⁴</td>
<td>10²</td>
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</tbody>
</table>

Figure 26: Photonic density of various sources. Photon flux for ultra-weak photon measurements is well below the threshold of the human visible range (~1·E6 s⁻¹·cm⁻²). Yet still, over the spectral range <700 nm, ultra-weak emissions are at least 1·E10 higher than the statistical Boltzmann distribution (Popp et al., 1988). Detection of such weak signals can only be obtained with a highly sensitive detector that has a low dark-count rate (modified after Oliver & Pike, 1968).

### Detection (1/6)

Figure 27: The elusive properties of ultraweak photon emission – very low intensities (Popp et al., 1988), ranging from a few to up to some hundreds photons·s⁻¹·cm⁻² along with their wide spectral occurrence, covering the UV- VIS-and near IR windows (van Wijk & Schamhart, 1988) – call for detection devices that meet these requirements.

Tools for detecting ultraweak photonic emissions
e.g.: 
i) PDA
ii) CCD
iii) MCP
iv) VLPC
v) STC
vi) PMT
vii) CMP

Micro-Channel plate …… mounted onto a Charged-Couple-Device

Figure 28: Nowadays, various detector types are available and range from photomultiplier tubes (PMTs) and channeltrons fitted with a photon-converting cathode to photodiode arrays (PDA) suitable for 1D-resolution - with the latter being of classical, of avalanche or of hybrid type that are widely used for standard optical detectors. For spatial (2D) resolution, both PDAs, charged-coupled devices (CCDs as used in digital cameras) and micro-channel plate (MCPs) can be used. MCPs are closely related to electron multipliers in that these intensify single photons by the multiplication of electrons via secondary emission. However, signal intensity of PDAs or CCDs can be boosted substantially by simply attaching an MCP on top of them [2]. Thus, MCPs are much more sensitive than comparable PDAs or CCDs and could one day become a real alternative to currently used PMTs.[1] Yet still, 2D-yield is much lower per detector element than in 1D-detectors as in the latter the full detector surface is used for photon capturing of the entire sample. In order to obtain usable signals, 2D-detectors require prolonged exposure as a reduction in detection area results in a drastic loss of integration time (the functional dependence is proportional to 1/d²).

Image:
Figure 29: More recent advances regard visible light photon counters (VLPCs) and the superconducting tunnel junctions (STCs) – both have good yield but require operation at almost absolute zero temperature. Since PMTs can be operated at reasonable conditions with a characteristic photon density yield of at least $2 \text{ photons s}^{-1} \text{cm}^{-2}$, they still remain the workhorses for ultraweak photon detection (Swain, 2010).

**Visible-light photon counters (VLPC)** are low-temperature semiconductor-based photon counting technology of single photons in the wavelength range of 400–1,000 nm. An electron–hole pair is generated in the undoped (intrinsic) Si absorber region, and the resulting hole triggers an avalanche in the gain region through interaction with As impurity levels. This single-carrier multiplication process only requires a small bias voltage of 6–7.5 V, but the device temperature must be carefully tuned to around 6 K to achieve optimal performance. As the avalanche is confined to a 20-μm-wide filament and the overall device diameter is 1 mm, two photons can produce distinct concurrent avalanches if the focal spot is large. VLPC detection efficiencies of up to 88% at 694 nm and 93% in the infrared have been observed, neglecting coupling losses and spectral filtering. The dark count rate is ~20 kHz at the maximum detection efficiency. The dead time of the VLPC is ~100 ns, and therefore the upper limit to the count rate is ~100 kHz. The jitter of these devices has recently been measured at 633 nm, and the lowest value obtained is 250 ps at FWHM in the dark count range of 6.9–25 kHz, with a maximum fibre-coupled detection efficiency of 40% (Hadfield, 2009).


Figure 30: Functional design of a classical Photo-Multiplier-Tube. It consists of a photon-electron converting photocathode to which a series of several dynodes are attached. The dynodes are connected to a voltage cascade that increases stepwise with each approach towards the anode. The latter can reach a potential of 2kV.[1]

Structure & operation principles of a **Photo-Multiplier-Tube** (PMT): PMTs are constructed from a glass vacuum tube, which houses a photocathode, several dynodes, and an anode. Incident photons strike the photocathode material, which is present as a thin deposit on the entry window of the device, with electrons being produced as a consequence of the photoelectric effect. These electrons are directed by the focusing electrode toward the electron multiplier, where electrons are multiplied by the process of secondary emission.

The electron multiplier consists of a number of electrodes, called dynodes. Each dynode is held at a more positive voltage than the previous one. The electrons leave the photocathode, having the energy of the incoming photon (minus the work function of the photocathode). As the electrons move toward the first dynode, they are accelerated by the electric field and arrive with much greater energy. Upon striking the first dynode, more low energy electrons are emitted, and these electrons in turn are accelerated toward the second dynode. The geometry of the dynode chain is such that a cascade occurs with an ever-increasing number of electrons being produced at each stage. Finally, the electrons reach the anode, where the accumulation of charge results in a sharp current pulse indicating the arrival of a photon at the photocathode.

**Detection (5/6)**

Tools for detecting ultraweak photonic emissions:
- PDA
- CCD
- MCP
- VLPC
- STJ
- PMT
- CMP

Advantages of CMPs:
1. Low background noise (due to different dynode design)
2. No charge-up effect of the housing (due to monolithic semi-conductive channel structure)
3. 2-D imaging if used in matrix

Disadvantage:
1. Small active window

In comparison to the classical PMT there are several advantages of the CPM technology:

- Due to different dynode design and except from thermal emission of the photocathode, CPMs have very low background noise.
- Rather than glass, the CPM-designs involves a monolithic semi-conductive channel structure, thus no charge-up effects occur.

With the absence of dynode noise, CMPs reveal very clean separation between real events created from a photoelectron and electronic noise, which leads to high stability of the signal over time. With active (window) diameters quite smaller than in classical PMTs – come in a variety of sizes, that range from several millimeters to few centimeters – CMPs can be used for 2-D imaging as well. An array of several CMPs in parallel provides a 2-D detector surface with a very coarse resolution. The drawback however, is its reduced surface area per detector, which translates into a 1/d² lower yield compared to a large 1-D classical PMT.


Figure 32: Schematics of Ultra-weak Photon Emission Detector.

**Amp:** signal amplifier;

**Ctrl:** Control-signal-link;

**DC:** dark chamber;

**Dis:** signal discriminator;

**DPU:** data processing unit such as a desktop computer;

**ES:** electronic shutter;

**FoC:** Fiber-optical cable link;

**M:** mirror;

**H:** temperature controller;

**HV:** high voltage supply;

**MC:** mono-chromator;

**PMT:** photo-multiplier-tube;

**PC:** Peltier-elements for cooling;

**PS:** standard power supply;

**SM:** step-motor;

**Xe-LS:** wide spectral Xenon-light source
Conclusion (1/1)

- UWPE-measuring technique is extremely sensitive and non-invasive;
- provides a new understanding of living systems and their complexity;
- enables in-vitro as well as in-vivo study of living systems;
- UWPE are an integrative, physically based approach, that has the potential of giving significant impulses to the interdisciplinary life-sciences.

UWPE helps to understand how living (dynamic) systems as multimode storage structures communicate (inter-, intra- and transcellular); regulatory processes regard:

• the spatially inhomogeneous energy-distribution structures biological matter;
• the flow of information affecting organization of biological matter;
• biological matter changes the spatial distribution of energy;
• feedback loop yielding a self-organizing (autopoietic) control of regulation processes;
• reg.-processes enabling growth in stability, leading to increased functional complexity;

Said all that …. The podium is open for discussion ….

Danke für Eure Aufmerksamkeit - Thanks for your attention

It is the aim of this chapter to present basic physical concepts for a better understanding of electromagnetic fields, and especially the concept of photons along with crucial properties, such as coherence. Since living organisms emit photons both within cells but also outside the body, it is assumed that biophotons play a crucial role in inter- and intra-cellular communication and in the organization of a living system. Such ultra-weak photon emission can be measured with devices called photomultipliers. This type of instrumentation has shown to be a reliable tool for diagnostic purposes within the field of biophotonics. Yet further research efforts and improved detector efficiencies are urgently required. Further improvement of this technology, for example regard enhancing photonic yield and signal to noise ratio. The emerging 2nd-generation detectors will enable exploration of biophotonic properties in living organisms even beyond existing limitations. This will both include measurements of the spectral intensities of biophotons emission as well as the biophotonic dynamics within cells there is no generally accepted evidence for physical coherence of biophotons
Fin
Matter in general and atoms in particular are standing waves “frozen in space and time”. Even the DNA is just a condensation of energy in which electrons of the macromolecule form a halo along the entire structure. Since all the electrons are delocalized, so too, must all the photons in the system be delocalized. Therefore, it is probably misguided and quite fruitless to try to identify from which specific chemical reactions biophotons originate.

Eine informationseinheit hat als günstigste flächenabmessungen mit einem millionstel cm² die dimension der zelloberfläche: auch die kohärenzlänge (die strecke, über die eine welle noch kohärent bleibt und der zusammenhang nur ihrem ursprung behält).... [1]


DICKE THEORIE: wenn die abstände der moleküle voneinander sehr gross sind, wird das licht spontan nach einer exponentialfunktion emittiert. Werden die abstände zwischen den molekülen klein im vergleich zur wellenlänge des lichts, dann verzweigt sich die spontane emission in zwei bereiche:

i) super-radiance: emission intensiver und stark verkürzt (konstruktive interferenz) und

i) sub-radiance: bei der das licht stark verzögert abgestrahlt wird (destruktive interferenz).

In beiden fällen ist das emittierte licht kohärent.

Die üblicherweise chaotische strahlung kann daher sowohl explosionsartig (»super-radiance«) als auch verzögert und stark abgeschwächt (»sub-radiance«) abgegeben werden. Die DNS erfüllt die Dicke-bedingung da die abstände mit 30pm sehr viel kleiner sind als die wellenlänge des sichtbares lichts in der grössenordnung von 500nm. Neueste experimentelle Ergebnisse der quantenoptik bestätigen dass diese fänomene auch umso ausgeprägter auftreten, je niedriger die intensität des lichts ist. Im bereich der biofotonen-intensitäten befindet man sich in einem optimalen lichtstärke-bereich, in dem das signal/rausch-verhältnis ungewöhnlich hohe werte annehmen kann.

Auch auf diesen zwei fänomen beruhen nach auffassung der biofotonen-forscher biologische funktionale ereignisse wie gruppeninformation und gestaltbildung in zellpopulationen der organismen (evtl. auch die genaktivierung fuer die expression des genotypeuss in den fenotypus).

Phonons: In physics, a phonon is a collective excitation in a periodic, elastic arrangement of atoms or molecules in condensed matter, such as solids and some liquids. Often referred to as a quasiparticle, it represents an excited state in the quantum mechanical quantization of the modes of vibrations of elastic structures of interacting particles. Animation: Normal modes of vibration progression through a crystal. The amplitude of the motion has been exaggerated for ease of viewing; in an actual crystal, it is typically much smaller than the lattice spacing.

Source: Bischof Marco; biofotonen – das licht in unseren zellen; 1995; 2001-verlag, FaM; FRG

BP operating at a Laser-threshold:

- far away from thermodynamic equilibrium,
- photon emission $Z_\lambda(T)$:
  \[ f_\lambda(T)_{\text{Biophotonie}} = \frac{Z_\lambda(T) \cdot \lambda^4}{8 \cdot \pi \cdot c \cdot F} \]
  \[ f_\lambda(T)_{\text{Planck}} = \frac{1}{h \cdot c} e^{-\frac{h \cdot c}{kT \cdot \lambda}} \]
- match only when emissions are present in quanta
  i.e.: $E_{\text{bio}} = h \cdot \nu_{\text{bio}}$

$\text{Urban & Schwarzenberg, 1979}$

---

$f = \text{CONSTANT PRINZIP}:[1] \text{ die mit } f \text{ bezeichnete kurve stellt die wellenlänge der schwarzkörper-strahlung im thermischen gleichgewicht dar mit abnehmender wellenlänge (zunehmender energie der fotonen) die wahrscheinlichkeit einer aktivierung von anregungszuständen exponentiell abnimmt (je kürzer die wellenlänge desto geringer der energiegehalt). Die besetzungszahl der biofotonen-strahlung ist praktisch nicht von der wellenlänge abhängig; d.h. dass die relevanten moleküle im biologischen system ihre angeregten orbitale unabhängig von deren energie mit gleich vielen elektronen besetzen; d.h. dass es sich um ein »ideal offenes system« handelt, das sich an der laserschwelle aufhält.}$

$f = \text{besetzungszahlen nach Boltzmann-statistik } f. T = 300K (\text{ca. 27ºC, therm. Gleichgewicht})$

$f_0 = \text{mittelwert verschiedener messungen}$

$f_1 = \text{unbehandelte Gurkenkeime;}$

$f_2 = \text{mit Cialith behandelte G.-keime;}$

$f_3 = \text{mit aceton vergiftete keime}$

Übereinstimmung der gleichungen nur wenn $E$ als quanten vorliegen (i.e.: $E = h \cdot \nu$), d.h. bei:[2]

- \text{thermodynamischen gleichgewicht ist die absorption = emisison (+ stimulierte emission), folglich tritt ein ENTROPIE-MAXIMUM auf (ordnungsminimum = TOD);} $

- \text{bei der nichtthermischen fotoemission ist die absorption \neq emisison (+ stimulierte emission), hier ist der zustand FERN vom thermodynam. gleichgewicht, es tritt ein ENTROPIE-MINIMUM auf (ordnungsmaximum), wie man es von der LASER-strahlung her kennt.}$

Source: Ruth B., Popp F.A.; 1976; Experimentelle Untersuchungen zur ultraschwachen Photonen-emission biologischer Systeme; Naturforsch. 31c, 741-745;


Spectral BP emission of germinating soy seeds:

- increase of mass does not match increase of photon emission
- BP emission is not necessarily correlated with increase by mass obtained by cell-division;

Ruth, 1976

Die biofotonen-emission wachsender sojakeime kennzeichnet in ihrem verlauf die verschiedenen organisationsformen der wachsenden keimlinge (blaue linie), eigenstrahlung der über acht tage wachsenden sojakeimlinge). In ähnlicher seise vergrössert sich auch die masse der keimlinge (rote linie), aber keineswegs so fein struk-turiert wie der fotonenstrom. **Es liegt nahe, die biofotonen als steuergrösse für das zellwachstum zu betrachten, und nicht umgekehrt, die zeitteilung als ursache fur biofotonen-emission anzusehen.**

Detection (5/6)

PMT Specs (R562 = R375):
- cathode radiant sensitivity
  64mA / W
- cathode luminous sensitivity
  150µA / lm
- anode luminous sensitivity
  80A / lm
- spectral range
  160 – 850 nm

Key Specifications:
- Part No          R562
- Type             Head on
- Size             51mm
- Active Diam.     46mm
- λ-Min            160nm
- λ-Max            850nm
- Peak Sens.       420nm
- Cathode Radiant Sensitivity 64mA/W
- Cathode Luminous Sensitivity 150µA/lm
- Anode Luminous Sensitivity 80A/lm
- Window           Quartz
- Cathode Type     Multi-alkali
- Red White Ratio  1:5
- Gain             5.3·E+05
- Dark Current after 30 min. 5nA
- Rise Time        9ns
- Transit Time     70ns
- Number of Dynodes 10
- applied H-Voltage 1000V
- Multi Anode      N