Experimental Evidence for the Fröhlich Hypothesis

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Abstract

Over the years, numerous experiments have been conducted with millimeter wave radiation; some of the data can be used to try and prove or disprove Fröhlich's Hypothesis. This paper gives an overview of experiments from both the Former Soviet Union (over the last decade) and more recent developments in the field and discusses the results.

Contents

1 Introduction

1.1 Why Millimeter Waves?

Radiation of cells with microwaves, and especially millimeter waves[1], is known to cause the temperature in those cells to rise and thus enable or influence biological processes such as growth.

It is, however, believed that millimeter waves cause a second kind of biological effects to emerge, unrelated to those caused by increased temperature (ie. at very low radiation intensity). The absence of coherent oscillations in the millimeter wave range in the natural environment – the absence of noise – would make that frequency band convenient for inter- and intra-cell communication.

H. Fröhlich formulated a hypothesis stating that energy in cells was not thermalized but instead stored in molecular vibration modes. According to his theory, coherent dipole vibrations generate an electromagnetic field that is used for long-range interactions between cells using water as a medium. This effect should be visible at normal temperatures and occur in all living things.

Specifically, Fröhlich's Hypothesis states that cells are able to recognize each other at a distance and be attracted or repelled. A second important part of the hypothesis is the vibrational model: trigger action of microwaves causing the excitation of coherent electric vibrations pumped by energy derived from metabolism. [Frö81]

Radiation of many biological effects with millimeter waves in the frequency region of 5×10^{10} Hz show sharp frequency resonances and have nonthermal effects on many biological activities. [Frö75]

Many speculations have been made referring to the Fröhlich model, and a large number of experiments has been carried out.

1.2 Organisation of this Paper

Starting from the "lowest level", physicochemical effects, and working its way up to the organism level, this paper strives to summarize experimental evidence for the existence or non-existence of effects according to Fröhlich's Hypothesis gathered over the last decade.

It relies on data from the Former Soviet Union, where research on millimeter waves has been pursued extensively, and current developments in the United States and England.

Since much of the data is taken from [PYP+98], it is reproduced here as short summaries or in tabular format to avoid unnecessary duplication.

[1] Electromagnetic oscillations in the range between 30 and 300 GHz

2 Physicochemical Effects

During the course of experimentation, specific effects of millimeter waves on water or biomolecular solutions have been found. They include:

- The Fourier Spectrum of a water capacitor charged with 18 V at 1 millisecond intervals showed two peaks at 5.25 and 46.8 Hz. Irradiation at 50 μW almost eliminated the latter peak and shifted the former peak to 6.75 Hz. Increase of the power to 5 mW produced similar, if less effective, results.
- Irradiation of distilled water at 51.5 GHz / 10 mW caused changes visible through holographic interferometry: the number of interference bands dropped by one while the distance between bands was increased 1.2-fold.
- Similar effects were visible – both faster and more profound – in a 2% human blood plasma solution. Dielectric permittivity and absorption coefficient of plasma could also be changed between 0.05% and 0.5% through irradiation. Percentages varied strongly between different samples. All effects were completely reversible.
- In water solutions, irradiation could cause a decrease in average temperature, either directly or after an initial increase. Another observed effect was the formation of a toroidal vortex, which would disappear after 30-40 minutes of irradiation and could not be reintroduced thereafter. It was also found that the amino acids *sarcosine* and *glycine* increase millimeter wave absorption at 5.84 and 7.12 mm.

Further studies showed that the specific absorption rate (SAR) of flat structures with high water content is, apart from radiation frequency, dependent on the following factors:

- temperature
- medium thickness – SAR in thin media may exceed that in thick media 10-fold
- presence of dielectric layers – increases SAR 2.5- to 20-fold, depending on the thickness of the medium

Fröhlich's model [Frö81] states that MMW radiation supplements the amount of biological pumping of energy, thus triggering biological effects which would have occurred at a later stage without the influence of radiation. Nonthermal action of microwaves at 2450 MHz seems to be established without a doubt.

3 Influence at the Subcellular, Cellular and Tissue Levels

[*Note: there have been many experiments with millimeter wave radiation that are irrelevant to the topic of this paper; therefore, they are not included here. This includes, for example, suppression of bioluminescence.*]

3.1 Effects on Human Erythrocytes

Rowlands et al. [RSL+81] noticed a small attraction between erythrocytes in plasma before their actual contact. The attraction was no longer detectable when the membrane potential was decreased to near zero, the ATP reserves were exhausted or cellular organization was deranged.

The paper cites this as evidence for Fröhlich's Hypothesis, especially since the effect is completely reversible (although it modifies structure and results in ion shifts). The membrane potential dropped from 15 to 7.1 mV after metabolic depletion, probably below a threshold for the Fröhlich effect[2].

The interaction causes cells even beyond the distances of Brownian motion to move towards each other and form into linear aggregates (*roleaux*). In experiments [RSE82], fewer than 30 cells remained unassociated after 15 minutes.

An assumption of the Smoluchowski theory is that all the particles are the same size; mixtures of erythrocytes from different species will aggregate when suspended in isotonic solutions of certain macromolecules – however, cells of the same size (and thus the same species) show a preference to adhere to each other. Experimentally, mixtures of dispersed embryonic heart and liver cells sort themselves out. [RSE82]

Embryonic stem cells are an important field in modern biological research. A major breakthrough would be the ability to use millimeter wave stimulation to cause stem cells to evolve into different organs, perhaps using data gathered from the above-mentioned experiments.

[2] This is unproven.

3.2 Effects on Growth Rate

Numerous experiments have been carried out concerning the influence on growth rate at the cellular level. In several cases, however, the experimental results could not be reproduced in later attempts, either due to lack of documentation or because of unknown but significant differences in the experiment set-up.

What follows is a list of the findings of MMW influence on growth rate; results that could not be reproduced are found at the end of the list and are marked with an asterisk.

organism	duration	wave	power	effects
S. cerivisiae	50 min	46 GHz	0.03 mW/cm^2	Fluctuation in growth rate
Barley seeds	20 min	61.5 GHz	0.1 mW/cm^2	36% increase in synchronized cell division
Spirulina platensis	30 min	7.1 mm	2.2 mW/cm^2	growth rate doubled, photosynthetic action increased 1.5-fold

- Influence on *Candida albicans* (yeast):

		wave		
modulation	duration	71.8 GHz	72 GHz	72.2 GHz
1 KHz	short-term	no change	15% less	no change
CW	long-term	no change	25% more	no change

- Influence on *Spirostum sp.*:

  Unexposed cultures on a saline medium with beer yeast died of waste product poisoning on the eleventh day of the experiment. The table below summarizes the effects of 30 minutes of 7.1 mm / 1.5 mW/cm^2 radiation:

day	effect
2, 4, 7	stationary phase entered on day 9; increased proliferation
9, 11	cells lived 5 days longer; slightly increased proliferation

  A similar experiment with a lower number of initial cells caused a much lower final cell density; this indicates that MMW radiation only influences the existing growth control mechanisms.

* In *S. cervisiae* and *S. carlsbergensis*, culture growth could allegedly be increased 2.3- to 6-fold and biomass production rate increased by up to 253%.

* In *E. coli*, both inhibitory and excitatory effects on growth were witnessed, depending on the wavelength (6.0-6.7 mm); similar results were reported for *S. cerevisiae* in the 41.8-42.0 GHz band, but could not be verified.

* Also in *E. coli*, lambda prophage growth (usually activated by UV or X-Ray radiation) could be induced with 70.5 GHz irradiation. [Frö81]

* The induction of Colicin can be significantly influenced by MMW radiation. [Frö81]

3.3 Effects on Proteins, Chromosomes and Genes

Experiments [Frö75] on DNA in weak electric fields have led to the conclusion that DNA does not have a permanent dipole moment; experiments in stronger fields, however, led to the conclusion of a permanent dipole. This supports the claim of highly polar metastable states made by Fröhlich's Hypothesis: excitation of the polar state would lead to breaking of electrical symmetry and have far-reaching biological effects.

According to Fröhlich, expected interaction frequencies at the protein level are between 10^{12} and 10^{14} Hz, while those for RNA and DNA are around 10^{9} Hz. [Frö81]

Measurements of proteins and amino acids showed exact cancellation of the intrinsic dipole moments of the individual amino acids in, for example, myoglobin.

Fröhlich suggests [Frö75] that protein conformation places charged groups outside to interact with water to account for the aforementioned cancellation. He mentions that one would expect minimal interaction energy, which has to go beyond nearest neighbour interaction – in fact, it requires interaction of charged groups. This could be significant for the self-organization of larger units, for example the attraction of a protein to a specific site; the pairing of homologous chromosomes during meiosis; the travelling of newly synthesized proteins to their destinations in the cell. [Frö81]

It has been conclusively proven that exposure to MMW does not cause mutagenic or recombinant effects in genes and chromosomes; there is evidence, however, that it might increase the probability of recombinant effects caused by ultraviolet radiation:

- *E. coli* were radiated at 58.9-63.1 GHz / 1 mW/cm^2 after exposure to UV, which increased the overall survival rate. No effect was noticed when the order of radiation was reversed.
- *S. cerevisiae* were radiated at 61.02-61.42 GHz / 0.13 mW/cm^2 for 30 minutes and later treated with UV; there was an increased number of gene conversions.

Thermal effects have not been ruled out as the cause of these changes.

A disputed experiment using the Anomalous Viscosity Time Dependence technique (AVTD) showed that sharp resonance in chromosomal structures could be caused by energies as low as $10^{-}19$ W/cm^2, peaking between $10^{-}17$ and $10^{-}8$ W/cm^2. Interpretation of this data is, however, uncertain, since AVTD is not normally used in cell biology.

3.4 Effects on Membranes

Biological membranes are usually around 10^{-6} cm thick and carry a potential difference of the order of 100 mV. The field is used in nerve conduction, but membranes of non-nerve cells also carry a potential difference. A section of the membrane oscillating represents an electric dipole; proteins built into the membrane may also oscillate at lower or higher frequencies.

Experimental evidence for this is summarized below, taken from [Frö78]:

- Synchronized cells supplied with an appropriate nutrient show a number of sharp, strong Raman lines in a range between 7×10^8 and 5×10^{12} Hz, ie. in the expected membrane frequency region[3].
- It was found that radiation effects at $4 - 6 \times 10^6$ Hz are subject to threshold properties: there exists a energy threshold S_0 so that any $S < S_0$ has no effect, while the effect is independent of S if $S > S_0$; furthermore, biological samples exhibit sharp frequency resonances.
- Fröhlich cites evidence for the importance of vibrations in the region of 5×10^{10} Hz; the strongest evidence from the Raman effect is at about 3×10^{12} Hz.

[3] However, it is not known whether they are caused by intermediate chemical products

Together with chromosomes, membranes are thought to be the major target for MMW radiation. A large number of studies and experiments is focused on membrane effects; the results are summarized in the table below.

[*Note: some experiments used intermittent exposure; these will be marked with* (IE/nn), *where* nn *is the number of minutes between exposures. All times are given in minutes, all frequencies in GHz and all powers in* mW/cm^2 *unless otherwise noted.*]

organism	duration	frequency	power	effects
SR, rat skeletal muscle	5	61	4	Ca^{++} uptake increases 23%. (IE/15)
	20			Ca^{++} uptake increases 27%.
	40			Ca^{++} uptake reaches 48%.
Ca^{++}-activated K^+ channels in kidney cells	20-30	42.25	0.1	Increases activity of channels with low initial activity and inhibits channels with high initial activity[4].
Giant alga cells	30-60	41, 50, 71	5	Chloride current drops to 0; no recovery for 10-14 h.
		49, 70, 76		Chloride curent increases 200-400%; reversible within 30-40 min.
Frog sciatic nerve	50-110	77.7	10	CAP[5]falls 10-fold; sensitization to frequency.
	?	41.14-41.54	0.02-2.6	frequency-dependent CAP decrease (bell curve).
Striatic muscle and cardiac pacemaker cells	1.5	54-78	0.1-0.15	Deceleration of transmembrane potential loss; reduction of overshoot voltage, action potential amplitued and conduction velocity.

Effects of MMW radiation in membranes is not monotonic; peaks of effects are not fixed at certain frequencies and change with the complexity of the organism involved.

3.5 Other effects

Other effects at low radiation, described by *Chernyakov et al.*, include synchronization of neuron "firing", enhanced respiration, reduction of contractility in cardiac cells and altered membrane calcium binding.

One of the speculations referring to Fröhlich's Hypothesis is the existence of co-

[4]These effects could be reproduced by exposing the membrane to irradiated bathing solution (30 minutes at 42.25 GHz / 2 mW/cm^2). There was no change in pH or Ca^{++} concentration of the solution. The mechanisms of this are not yet understood, but highly promising.

[5]compound action potential

operative oscillatory dipole states in a particular stage of their life. [RBP81] showed experimentally that cells in their reproductive state attract highly polarizable particles more than poorly polarizable particles, decreasing with the increase of the conductivity.

4 Influence at the Organism Level

As millimeter waves do not penetrate the skin deeply, reactions at the organism level are believed to take place at the skin or shallow subcutaneous regions. They are then *somehow* propagated, but it is currently not understood how. Indeed, there is no obvious connection between cellular-level and organism-level reactions; the subject remains open for speculation.

4.1 Effects on Receptors

One of the propagation theories believes peripheral receptors and their nerves to be responsible for the propagation of MMW effects. The following table summarizes the experiments carried out on peripheral receptors.

[*Note: All times are given in minutes, all frequencies in GHz and all powers in* mW/cm^2 *unless otherwise noted.*]

area	duration	frequency	power	effects
electroreceptor Lorencini	?	33-55	1-4	increased firing rate
			10+	inhibition of firing
rat upper thoracic vertebrae	20	55, 73	$\leq$10	arrhythmia, no changes in body temperature
	150	51, 61, 73		sudden death
frog bladder	20	42.04-42.34	10	alterations of spontaneous afferent firing in the bladder nerve
rat skin mechanoreceptors, hind limb sole	35	55	0.75	changes in threshold and latency in response to stimuli
		61	2.90	
		73	7.81	

In addition, heart rate changes in frogs could be induced by irradiating remote skin areas, even if the heart was entirely denervated.

In experiments with humans, 30-80% of test subjects could detect exposure of the hand to MMW radiation (37.7, 42.25, 53.57 GHz at 5-15 mW/cm^2); higher frequencies caused more subjects to detect radiation than higher power.

Fröhlich mentions [Frö81] that electric fields at 10-20 Hz, as well as in the microwave region, can influence the EEG severely; during certain periods, large regions of the brain oscillate coherently.

4.2 Animal Studies

Suprisingly few animal studies were carried out by researchers in the former Soviet Union; what little material there is mostly concerns itself with the influence of MMW radiation on surface wound healing processes.

4.2.1 Influence on Surface Wounds

- While exposure of septic or aseptic wounds to modulated MMW radiation caused an increase of inflammation, continuous wave (CW) radiation resulted in significantly reduced healing time: in an experiment with rabbits, irradiated aseptic wounds took 2.9 days less to heal; septic wounds healed 7 days faster than in non-irradiated animals.
- Swelling of wound edges, hyperemia, infiltration and bacterial contamination were reduced while phagocytosis was stimulated.

4.2.2 Influence on Organism Self-Repair

- One experiment dealt with artificial bone defects in rabbits; again, MMW radiation caused an increase in reparative osteogenesis in exposed animals, speeding up healing effects by 7 days.
- Damaged peripheral nerves irradiated for 10 minutes every three days showed a minor, yet statistically significant increase in regeneration distance and nerve conduction velocity.

4.2.3 Influence on Tumor Growth

Fröhlich believes [Frö78] that a cell which has lost its correct vibrational frequency can no longer contribute to a collective vibration and might disrupt the cell division control barrier, causing tumor growth if more and more cells go out of synchronization. This is highly speculative at best, and no evidence exists.

- VMR tumor cells were introduced into mice and the animals were irradiated at 7.09-7.12 mm, 12.5 mW/cm^2 for five days (1 hour/day). The number of visible metastases was reduced by more than 50% while the average life span of animals increased by 17%.
- Walker tumor cells were introduced into rats and the animals were irradiated with 43 nanosecond pulses (40 second intervals) at 8 mm / 4-5 MW and 5 mm / 8-10 MW. The first experiment caused 1.5-fold reduction of tumor growth, increasing the lifespan by 17-25 days, while the second experiment was much less effective. Irradiation before introduction of the tumor cells reduced the growth two-fold.
- While researching possible negative effects of MMW radiation on tumor growth, *Brill* and *Panina* discovered that irradiation did not affect tumor proliferation.

4.2.4 Other Findings

Several other experiments were conducted, and the findings are summarized below.

- In experiments with immobilized rats, it was found that MMW radiation caused anti-stress effects when the animals were irradiated for 30 minutes, but not when irradiatied for 60 minutes. There is not yet any explanation for the decreased effects of longer exposure, which could also be observed in several other studies.
- MMW radiation was found to alleviate the effects of X-rays in rats at both the cellular and the organism levels.
- When rats exposed to γ-radiation were treated with MMW prior to contamination, the membrane structure of erythrocytes was stabilized and its resistance to γ rays increased.
- MMW treatment for 80 hours before exposure of mice to a lethal dose of X-Rays (7 Gy) increased lifespan from an average of 6-8 days. The first fatalities were observed after 14 days; 50% of the animals were dead by day 30, and it was only on day 96 that the last mouse perished.

  Treatment for 24 hours prior to exposure proved even more efficient, with 50% dead by day 30, but no further fatalities until day 96. However, the effect decreased with increasing X-Ray intensity, until it all but vanished at a dose of 8 Gy.

  MMW irradiation at the same time as X-Ray irradiation increased the lifespan five-fold.

4.3 Clinical Studies

It is interesting to note that while few studies of effects on animals exist, the Russian government has officially approved MMW therapy, and more than 3,000,000 people were treated in hospitals and specialized centers between 1977 and 1995 (the date of the

report by *Lebedeva* and *Betskii*). There are hundreds of publications on the clinical use of MMW radiation and a commercial market for MMW generators.

4.3.1 General Information

Depending on the patient's illness, the location, wavelength and duration of irradiation are selected by the physician. "Standard" values for most diseases vary between 15 to 60 min/day for 8-15 days.

Three models are used frequently:

- 42.19 GHz, 10 mW/cm^2
- 53.53 GHz, 10 mW/cm^2
- 59-63 GHz, 10 mW/cm^2

The effects of MMW radiation are disputed: while many authors claim that MMW monotherapy was able to help even patients with incurable diseases and hardly ever showed any side effects, others claimed that the success depended very much on the patient's condition and sensitivity to the radiation. Yet another group of studies claims that MMW was inferior to conventional therapy every time, and there are even studies claiming MMW radiation did not have any effects whatsoever.

The following list of conditions reportedly successfully treated with MMW radiation must therefore, in light of the above, be taken with a grain of salt (and it may indeed seem that nothing was left off the list):

- cardiovascular diseases – angina pectoris, hypertension, ischemic heart disease, infarction
- respiratory sicknesses – tuberculosis, sarcoidosis, bronchitis, asthma
- skin diseases – wounds, trophic ulcers, burns, atopic dermatitis
- asthenia
- neuralgia
- diabetes mellitus
- osteochondrosis
- acute viral hepatitis
- glomerulonephritis
- alcoholism
- toxic effects of chemotherapy
- preventive medicine

- health resort therapy
- ...

4.3.2 Problems

About 30% of studies report the use of MMW therapy on either known acupuncture points or areas to which the patient proves sensitive. Therapeutic effects could be explained by thermal effects, as an intensity of 10 mW/cm^2 may be enough to cause acupuncture- or acupressure-like effects through heating.

No rationale for the use of the above-mentioned frequencies and intensities or the application to certain skin areas could be found; unfortunately, many studies do not conform to traditional quality criteria and must be used with caution.

4.3.3 Examples

- Low intensity MMW radiation was found to have a positive influence on postoperative wound treatment: clearance of purulent wounds after abdominal surgery was 1.8 times faster, the onset of granulation and epithelization 1.8 times earlier than in untreated patients; average daily reduction of wound surface area was twice as fast in irradiated skin areas.
- Stomach ulcers healed in 95.3% of MMW-treated patients within 19-20 days; in untreated patients, only 78% of ulcers healed after 32-34 days. Furthermore, relapse in treated patients was significantly lower.
- MMW therapy for patients with angina pectoris caused a substantial decrease in the rate and severity of angina attacks, whether or not additional medication was taken.
- In patients with cerebral circulatory disorders, MMW therapy caused positive effects in 70% of patients (decreased blood pressure, normalization of blood glucose level, elimination of serum fibrinogen B), as opposed to 40% in those treated with medication only.

4.3.4 Side Effects

MMW radiation is generally well tolerated by patients, though some studies claimed side effects in up to 26% of patients. Local low-power MMW irradiation is believed to cause adversary health effects and requires special attention.

Reported side effects in treatment of cardiovascular diseases in 200 patients, while facilitating recovery in 56-77% of cases (depending on pathology), included the following:

# of cases	side effect
9	elevated blood pressure
7	diencephalic crisis / paroxysm
6	enhanced menstrual bleeding
5	fever
3	angina attacks

Reported side effects in treatment of stage II essential hypertension in 124 patients included the following:

# of cases	side effect
33	blood pressure fluctuations, headaches
16	reactions of the autonomous nervous system[6]
6	sleepiness, nightmares, weakness, irritability
2	hypertensive crisis

In therapy of 528 patients with various diseases, three patients developed hives after 5-7 days of treatment; it spread over the whole body, but disappeared 2-10 days after the treatment ended. The reason is unknown.

[6] whole-body shivering, sweating, heart pains together with skin paling or reddening

5 Conclusion

In many of the studies summarized in the previous chapters, effects markedly different from those caused by heating have been found; in others, the power of MMW radiation was too low to cause thermal effects.

The problem with publications from the former Soviet Union is their reliability, since (as previously mentioned) many are flawed in one way or another, most of the time missing control mechanisms such as sham-exposed control groups, a double-blind component in which neither researcher nor patient know whether the treatment is a placebo or exact specifications of the conditions in which the experiment was performed.

The reasons why millimeter wave radiation works are unknown; Fröhlich's Hypothesis tries to explain. Unfortunately though, the effects of MMW can not be conclusively proven to be caused by long-range communication of cells, even if the hints are strong – irradiation of skin causing changes in internal organs, for example.

Fröhlich's Hypothesis will have to remain a hypothesis for the time being.

6 Bibliography

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