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Microwave Induced Hormesis

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Abstract

The effect of centimeter waves of non-thermal level on four types of bacteria has been studied. On *E. coli* strains, a sharp increase in survival during the first cycle of cell division was obtained. The mechanism of inhibition of pathogenic bacteria by a weak electromagnetic field is explained. The mechanism of stimulating the survival of bacteria associated with the activation of genes that reduces the number of dying bacteria is explained. The general form of the modified Ferhulst equation is proposed and its general solution is found, taking into account the impact of negative external influences and the effect of stimulation. Conclusion: A weak electromagnetic field can be used in sanitary procedures, and the modified Ferhulst equation can help in the preparation of treatment programs.

Subject Areas

Biophysics, Cell Biology, Pathology, Pharmacology

Keywords

Bacteria, Survival, DNA, Resonance, Stabilization, Genes, The Ferhulst Equation

1. Introduction

The effects of the Electromagnetic Field (EMF) on living systems are manifested at all levels: molecular, genetic, systemic, and population. For example, a swarm of bees or a flock of fish is more sensitive to the field than single individuals.

Stimulation or suppression of the activity of living systems under the influence of EMF has a general character. For example, an increase in the motor activity of a larger unicellular, infusoria *Spirostotnum ambigiium*, was found when exposed to weak EMF with frequencies of 8.82 - 9.95 GHz at a power flux density of 0.2 mW/cm^2 and an exposure time of 1 - 10 min. With an increase in the EMF frequency to 10.4 GHz and exposure time to 20 - 30 minutes, a decrease in motor activity was observed [1]. Exposure to intense picosecond pulses of 0.5 THz at a voltage of 220 kV/cm and 70 kV/cm in human skin cells involved in tumor and inflammatory processes causes favorable coordinated changes in the activation of many genes [2].

The effect of an alternating magnetic field on the head of elderly rats led to the fact that the rough coat was replaced by soft and thick, the eyes became bright pink, the skin was soft and elastic, and the irradiated individuals differed from the young only in size. The females had a return to a normal sexual cycle. To maintain the effect, it was enough to repeat the irradiation session [3].

Previously, it was assumed that the acceleration phenomenon is associated with the widespread introduction of radio [4]. In those countries where mobile communication is spreading especially intensively, in Germany, Denmark, and Great Britain, since the beginning of the spread, from 1984-1987, there has been an acceleration in the growth of life expectancy in comparison with other countries.

An increase in the activity of living systems under the action of negative factors has been called hormesis—the stimulation of any system of the body by external influences, the moderate doses of stressors having a force insufficient for the manifestation of harmful factors. Hormesis can be caused by toxins, medicines, harmful environmental agents and physical factors used in radiation technologies.

Depending on the frequency, the density of the EMF power flux and the exposure time, EMF exposure can lead to suppression of cell growth, their death, but it can also have a stimulating effect, that is, a sharp increase in the number of microorganisms.

In [5], it was found that the effect of ionizing radiation on microorganisms depends on the amount of absorbed dose. In small doses, a stimulating effect is manifested.

The division of *E. coli* (*Escherichia coli*) under the influence of EMF with frequencies of 8.55 and 9.22 GHz is accelerated by about 30% [6]. However, this is an insignificant increase, which is covered by the error of the calculation method and cannot indicate hormesis.

When irradiating microorganisms with broadband visible light, a stimulating effect was revealed. The cells of *E. coli* M-17 served as the object of exposure [7] [8].

In [9], an increase in the survival rate of *E. coli* with short-term exposure to weak microwave EMF was obtained.

The question arises: to what extent does the stimulation of bacterial survival under the influence of microwaves have a general character? Secondly, can, therefore, the phenomenological Ferhulst equation describe this type of hormesis? The purpose of this study is to modify the Ferhulst equation in such a way that it takes into account hormesis, and secondly, to study the phenomenon of hormesis caused by microwaves.

2. Theory

The standard Ferhulst equation has the form:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = rN\left(1 - N/K\right) \tag{1}$$

where N is the number of bacteria, the coefficient r characterizes the rate of reproduction, K is the maximum possible population size.

Here, the member reflects the competition for resources. At the maximum of the number, the growth of the culture stops. Solutions of the equation:

$$N = KN_0 \mathrm{e}^{rt} \Big/ \left[K + N_0\left(\mathrm{e}^{rt} - 1\right)\right]$$

With the exhaustion of resources ($t \to \infty$), the difference $K - N$ decreases exponentially with the same indicator as with exponential growth. The graph of the dependence of the number of bacteria on time first increases exponentially, then reaches a plateau when the number of newly appeared cells coincides with the number of dead cells, then drops to zero.

The evolution of bacterial cultures can be divided into eight phases: the dormant phase (from the moment of sowing), the phase of delayed reproduction (the phase of bacterial growth, the lag phase), the logarithmic phase (exponential growth in numbers), the phase of negative acceleration, the stationary phase of maximum (plateau, the number of dead is equal to the number of formed), the phase of accelerated death, the phase of logarithmic death, the phase of decreasing the death rate.

By analogy with demography, we will introduce fertility and mortality rates. Then, the coefficient r in Equation (1) is the difference between fertility and mortality, and mortality also increases due to the competitive term rN^2/K.

In the case of exposure to a short-term external depressing factor, mortality may increase, that is, the coefficient r, characterizing the rate of reproduction, decreases. If the external factor temporarily increases survival, then the coefficient r in the first term increases. Such a process can be modeled by the following equation:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = \left[r + \theta\left(\tau - t\right)f\right]N - rN^2/K$$

where θ is the Heaviside function, the value of f characterizes the number of stabilizing cells.

The surge in survival has the form of a bump on a plateau. In general, the constant coefficients in the Ferhulst equation, characterizing mortality and fertility, turn into functions of time, the equation itself takes the form of the Riccati equation:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = \left[r + c\left(t\right)\right]N - b\left(t\right)N^2 \tag{2}$$

where c is a time-dependent coefficient characterizing either the suppression or stimulation of bacteria by an electromagnetic field, b is a time-dependent "competitive" coefficient, $b = r/K$.

Let us denote $a = r + c\left(t\right)$, thus, the growth parameter becomes time-dependent and contains functions of survival dependence on external stress factors. Then

$$\frac{\mathrm{d}N}{\mathrm{d}t} = a(t)N - b(t)N^2 \tag{3}$$

The dependence of functions *a* and *b* on time is determined by the nature of bacteria, external influences, including temperature, resource limiting factor and is determined from experimental data. The solution of Equation (3) has the form:

$$N(t) = \frac{\mathrm{e}^{\int_1^t a(x)\mathrm{d}x}}{c_1 - \int_1^t b(y)\left(-\mathrm{e}^{\int_1^y a(z)\mathrm{d}z}\right)\mathrm{d}y} \tag{4}$$

It follows from Equation (4) that not all coefficients *a* and *b* can give a surge in survival on the 1st cycle of division and the death of bacteria on the 6th cycle of division. For example, such an external influence as an increase in temperature does not cause a surge (hormesis), but an almost uniform increase in the survival rate of bacteria. On the contrary, if, say, the culture of *E. coli* is quickly heated to 38 degrees, it will die at the beginning of the 1st cycle of cell division.

Thus, a and b are functions of exposure time, frequency of the external electromagnetic field, temperature, as well as other factors, DNA length, exposure to light, etc.

3. First Two Experiments

The phenomenon of hormesis under the influence of microwaves has been studied on the examples of mycobacteria and *E. coli*.

1) Mycobacterium avium, bacteria similar in structure to the Koch stick, *M. avium* 104 (subsp. hominissuis) isolated from the blood of HIV-infected people, as well as Koch's bacillus, *Mycobacterium tuberculosis* H37RV (Pasteur) ATCC 25618.

The test tube with the experimental strain was irradiated, the test tube with the control strain was placed next to it, but it was not irradiated.

The experimental and control strains were isolated from exposure to daylight.

Bacterial strains were cultured on Finn II egg medium.

An Agilent Technologies E82570 1 microwave generator was used to irradiate bacteria, a power flux density of 2.5 MW/cm^2 was selected, which does not cause heating of bacterial cultures.

The value of the EMF frequency of the generator was theoretically determined, it was set equal to the natural (resonant) frequency of torsional vibrations of the helix of various DNA. The fact is that when the frequency of the generator coincides with the resonant frequency of the torsional vibrations of the DNA helix, the DNA molecule is excited, which prevents DNA replication (doubling), hence cell division, dramatically increases the number of single-strand breaks and suppresses DNA repair systems, as a result of which the cell dies. This frequency is inversely proportional to the square root of the number of nucleotide pairs of the cell's DNA: $w = 21.75/\text{sqrt}(BP)$ in TGz, where *BP* is the number of nucleotide pairs in DNA.

The nucleotide sequence of the DNA of the *M. avium* 104 strain consists of 5,475,491 pairs of nucleotides, respectively, the resonant frequency of torsional vibrations of the *M. avium* 104 DNA molecule is 9.3 GHz. The DNA length of *Mycobacterium tuberculosis* H37RV is 4,411,529 nucleotide pairs, the corresponding frequency is 10.36 GHz.

The maximum exposure time was chosen equal to 6 cycles of cell division. Since the cell division cycle in *M. avium* 104 is approximately 1 hour, the maximum exposure time was chosen to be 6 hours.

The cycle of cell division of *Mycobacterium tuberculosis* H37RV is more than 18 hours, so the maximum exposure time was set to more than 108 hours - 114 hours.

The irradiation was carried out at 25 degrees.

The first test tube was irradiated for 1 hour, the second for 2 hours, etc. The survival rate was determined: the number of bacteria in the test tube was divided by the number of bacteria in the control tube; the result was multiplied by 100%.

2) In 10 experiments with *M. avium*, it was found that after the expiration of the first cell cycle equal to 1 hour, the survival rate increased to (173.6 ± 14.7)%.

3) In 10 experiments with Mycobacterium tuberculosis, it was found that after the expiration of the first cell cycle, equal to 19 hours, the survival rate increased to (172.7 ± 19.3)%.

Deviations from mathematical expectations are obtained in a standard way, for probability P = 0.95.

4. Analysis of the First Two Experiments

The fact that hormesis under the action of microwave EMF at the first cell cycle manifests itself in two different types of mycobacteria, and in the same way, suggests that the mechanism of this type of hormesis is a single one. The only reasonable assumption that does not contradict the experiment and logic may be the following: the same part of the bacteria that should have died, the microwave EMF stabilizes. That is, the external field does not increase the growth factor *r*, but reduces the "mortality" *c(t)* in the coefficient $a = r + c(t)$ in Equation (3). Stabilization concerns DNA, which accelerates cell metabolism under stress. Further irradiation leads to a decrease in survival, which corresponds to the concept of hormesis.

So an approximate graph of the solution of the modified Ferhulst equation under the external influence of microwaves looks like this (**Figure 1**).

In [10], only a slight increase in survival under red light and no changes when exposed to green light were obtained. The authors explain the effect of increased survival by the fact that when red light is absorbed by superoxide dismutase molecules, their activity may change. When irradiating prokaryotic cells, namely *E. coli* M17 bacteria, terminal enzymes of respiratory chains can serve as photoacceptors.

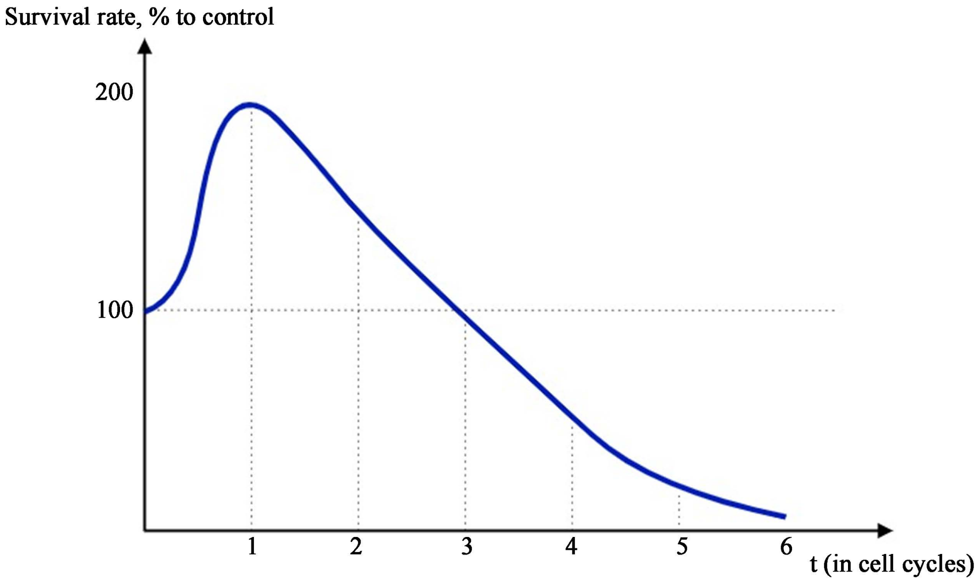

Figure 1. Dependence of bacterial survival on time in cell cycles.

At the same time, it was found in [9] that red and blue light, on the contrary, reduce the survival of *E. coli*. Thus, the data are contradictory, which suggests that daylight can hardly be stressful, rather, it is a favorable factor.

In [9], the effect of microwave in the range from 8.82 GHz to 10.4 GHz at a power flux density of 0.2 mW/cm^2 on cells of the mutant strain of *E. coli* hcr'exr' and wild strain of *E. coli* WP2 was also studied. With an irradiation time equal to one, two and three cell cycles at frequencies of 8.82 GHz, 9.14 GHz, 9.97 GHz, 10.4 GHz, including at resonant 10.14 GHz, hormesis was absent.

Thus, with such a low power flux density, centimeter waves are too weak a stress factor to cause hormesis.

On the other hand, as shown in [7], irradiation of *E. coli* M-17 at a frequency of 9.372 GHz with an exposure time of 60 minutes, but with a significantly higher power flux density, from 3.4 to 27.2 mW/cm^2, hormesis also did not occur.

At the same time, at intermediate power 2 mW/cm^2 densities, hormesis took place when *E. coli* was irradiated with EMF at a frequency of 3.07 GHz [11].

Consequently, the number of parameters on which the functions a and b in Equation (4) depend also includes the power flux density.

Can hormesis occur with prolonged exposure to stress factors?

5. Third Experiment

E. coli ATCC 25922 was selected for experiments.

A fresh (daily) culture, on a meat-peptone broth was used. With the help of sterile saline, a working dilution was prepared. The daily broth culture was divided into 2 parts, control and experimental, then diluted to concentrations acceptable for crops. For the purity of the experiment, the growth of the culture was stopped, for this purpose it was diluted with a sterile saline solution of 1:100, so that its density was at about 10^7 CFU/ml, respectively, after processing, five

10-fold dilutions were prepared and sown from the last three. After irradiation of the experimental samples, the preparation of samples is carried out, that is, the preparation of consecutive 10-fold dilutions from 10^{-1} to 10^{-6}.

Sowing from the last 3 - 4 dilutions was carried out with a lawn on a dense nutrient medium (Petri dishes with meat-peptone agar) 0.1 ml of dilutions 10^{-6} and 10^{-7} of control and experimental samples in two repetitions. The cups were placed in a thermostat for 24 hours at a temperature of 37˚C. The results were taken into account by counting colonies in cups (the arithmetic mean obtained when counting colonies on two cups of the corresponding dilution was used), the concentration of microorganisms in the sample was recalculated (taking into account the dilution and the sowing dose).

The exposure time is 180 minutes, more than 6 cell cycles. The test tubes were insulated with black paper with the absence of heavy metals in the black paint, so as not to shield the microwave EMF. The ambient temperature was 24˚C, controlled by a thermometer and changed during each experiment by no more than 0.5˚C. The same microwave generator with the same parameters was used.

It was found that irradiation with microwave EMF for a long time, more than one cell cycle, does not lead to hormesis (**Table 1**, 2nd line). However, with simultaneous exposure to microwave EMF and daylight (**Table 1**, 3rd line), hormesis takes place, and the dependence on frequency is periodic.

In experiments with *E. coli* M17, when irradiated with light and EMF at frequencies of 9.8 GHz, 10.07 GHz, 10.27 GHz (resonant), 10.47 GHz, 10.67 GHz, hormesis was observed at frequencies of 10.07 GHz and 10.47 GHz, survival increased to (189.2 ± 31.4)% and (179 ± 5.6)%, respectively.

For both strains of *E. coli*, hormesis occurs not on the 1st, but on the 6th cycle of cell division.

Both additivity and synergism of combined stress factors [11] and their antagonism are known. However, in this case, daylight has a constant stimulating effect, so it shifts the hormesis in time.

As expected, with prolonged exposure, EMF radiation at a resonant frequency no longer causes hormesis, but radiation at frequencies close to resonance when combined with visible light plays the role of a weak stressor.

A similar type of hormesis can be approximated by the Ferhulst equation if the dependence of the coefficient $a = r + c(t)$ on frequency is represented as a periodic function, $a(f) = a(f + 0.4n)$, where frequency f is in gigahertz, n is an integer.

Table 1. *E. coli* survival rate when exposed to microwaves and microwaves with light.

Frequency, GHz	9.2	9.4	9.6	9.8	10.0
CFU/1 ml, from the initial number, %	42.5 ± 5.5	60.0 ± 7.4	22.5 ± 3.28	70.5 ± 9.5	110.5 ± 8.3
+ light	72 ± 12.7	187.0 ± 23.6	76.5 ± 6.4	170 ± 8.9	133.5 ± 4.5

6. Conclusions

1) The resulting Ferhulst equation describes the evolution of bacterial culture taking into account the hormesis that occurs due to the stabilization of dying bacteria, reducing "mortality".

2) The experiment shows that microwaves with a frequency coinciding with the natural frequency of torsional vibrations of bacterial DNA helices cause hormesis after the first cell cycle, and to the same extent in both *M. avium* and *Micobacterium tuberculosis*.

3) Moreover, hormesis does not occur at other frequencies, and secondly, irradiation with exposure greater than one cell cycle leads to a sharp decrease in the survival of bacteria after 6 cell cycles.

4) A completely different picture arises when simultaneously irradiated with microwaves and daylight. Suppression of survival after 6 cell cycles is almost not observed, on the other hand, hormesis occurs after 6 cell cycle at frequencies symmetrically close to the resonant frequency.

Increasing the survival rate of bacteria under the influence of a weak electromagnetic field can be used, for example, to increase the mass of bacterial cultures needed in various fields: pharmacology, medicine, and food industry. The modified Ferhulst equation will allow us to establish the characteristics and time of external influences for hormesis.

Bacteria have a hierarchy of repair systems, including a cellular DNA repair system, for example, excision repair of nucleotides, mismatch repair, etc. The effect of photoreactivation was discovered by A. Kelner and A. Dulbekko. Aziz Sanjar discovered that under the influence of blue light, DNA photolyase is activated in the cell, which heals DNA damage resulting from the action of hard UV (UV-A), and removes pyrimidine-pyrimidine dimers arising in DNA [12]. DNA photolyase acts as a cofactor, a donor to break dimers.

In our case, instead of the action of a hard UV, the action of a microwave. It is possible that: 1) either dimers are formed under the action of microwave, 2) or other damages are formed under the action of microwave, which are healed by DNA photolyase, 3) or there are any damages that are eliminated by the DNA self-repair system activated by UV-B. That is, it is not cellular repair systems that are activated, but DNA self-repair.

Probably, ultraviolet light with a frequency at the border of ultraviolet-A and ultraviolet-B, which is not absorbed by glass, can have a stimulating effect on mitosis. The energy of this UV is located close to the middle of the forbidden zone of the DNA base level system in the quasi-periodic crystal model [13]; therefore, the effect of increased survival may be associated with the resonant absorption of the DNA levels of the boundary UV by the system.

Hormesis can be widely used in medical investigations, for example, radiation hormesis can be used in the treatment of oncology [14].

A local increase in temperature can suppress the growth of malignant neoplasms. This increase may be caused by the hormesis of some bacteria inside the body. The Ferhulst equation can help, without putting additional experiments, to make a treatment program.

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Conflicts of Interest

The author declares no conflicts of interest.

References

[1] Antipov, S.S. (2007) Influence of Microwave EMR on Regulatory Systems of *Escherichia coli*: Abstract. Diss. Cand. Biol. Sciences, Pushchino, 109 p.

[2] Titova, L.V., Ayesheshim, A.K., Golubov, A., Rodriguez-Juarez, R., Woycicki, R., Hegmann, F.A., *et al.* (2013) Intense THz Pulses down Regulate Genes Associated with Skin Cancer and Psoriasis: A New Therapeutic Avenue? *Scientific Reports*, **3**, Article No. 2363. https://doi.org/10.1038/srep02363

[3] Garkavi, L.H., Kvakina, E.G. and Ukolova, M.A. (1979) Adaptive Reactions and Resistance of the Organism. Rostov-on-Don State University, Rostov-on-Don, 128 p.

[4] Presman, A.S. (1968) Electromagnetic Fields and Wildlife. Nauka, Moscow, 288 p.

[5] Chizh, T.V., Kozmin, G.V., Polyakova, L.P. and Melnikova, T.V. (2011) Radiation Treatment as a Technological Technique to Increase the Level of Food Security. *Bulletin of the Russian Academy of Sciences,* No. 4, 44-49.

[6] Geraskin, S.A. and Kozmin, G.V. (1995) Assessment of the Effects of Physical Factors on Natural and Agricultural Ecological Systems. *Ecology*, No. 6, 419-423.

[7] Monich, V.A., Malinovskaya, S.L., Makhrova, T.V. and Malinovsky, D.S. (2010) Features of the Effect of Low-Intensity Electromagnetic Radiation of Various Ranges on Microorganisms. *Bulletin of the Nizhny Novgorod University*, No. 2, 435-438.

[8] Tiphlova, O.A. and Karu, T.J. (1988) Stimulation of *Escherichia Coli* Division by Low-Intensity Monochromatic Visible Light. *Photochemistry and Photobiology*, **48**, 467-471. https://doi.org/10.1111/j.1751-1097.1988.tb02847.x

[9] Kozmin, G.V. and Egorova, V.I. (2006) Stability of Biocenoses in Conditions of Changing Electromagnetic Properties of the Biosphere. Biomed. Technologies and Radio Electronics. *Open Access Library Journal*, **3**, 61-72.

[10] Malinovskaya, S.L., Monich, V.A., Pyatova, E.D., Lyutov, S.I., Lazukin, V.F., Malinovsky, D.S. and Yu, A.S. (2011) The Effect of Radio Waves on Lysogenic Cells of *E. coli* and Bacteriophage. *Bulletin of the Nizhny Novgorod University Named after N.I. Lobachevsky*, **2**, 90-93.

[11] Yanutsevich, E.A., Danilova, O.A. and Tereshina, V.M. (2020) Combined Effect of Various Stress Factors on the Composition of Membrane Lipids and Osmolytes of *Aspergillus niger*. *Microbiology*, **89**, 410-418. https://doi.org/10.1134/S0026261720040153

[12] Sancar, A. (1994) Structure and Function of DNA Photolyase. *Biochemistry*, **33**, 2-9. https://doi.org/10.1021/bi00167a001

[13] Ikhlov, B.L. (2018) Application of Radioprotectors in Gerontology. *Bulletin of New Medical Technologies*, **25**, 209-215.

[14] Oakley, P. (2015) Is Use of Radiation Hormesis the Missing Link to a Better Cancer Treatment? *Journal of Cancer Therapy*, **6**, 601-605. https://doi.org/10.4236/jct.2015.67065