Doubts about Nonthermal Effects of MM Radiation Have no Scientific Foundations

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Abstract. All causes of doubtings nonthermal effects of MM radiation are reviewed in details, including problem of reproducibility of outcomes. On the basis of the thermodynamic theory of electromagnetic radiation energy conversion is shown, that they are fine confirming of prognoses of the thermodynamics for conversion of energy in the Rayleigh - Jeans region.

Discovering of nonthermal effects of MM radiation

The first bieffects of radiofrequency radiation were observed more than 100 years ago, but their systematic study was begun much later, in the middle of 20th century with focus on the thermal bioeffects of microwaves. On Jan. 17-18, 1973, there was a scientific session of the Division of General Physics and Astronomy of the USSR Academy of Science in Moscow. At this session, Academician N.D. Devyatkov reported for the first time frequency-dependent nonthermal biological effects in the frequency range from 39 GHz to 60 GHz [1]. These effects were observed at the different levels of living matter organization (molecules, cells, organ, and organism). Results were arrived by different experimentalists in laboratories of different institutes under direction of Acad. Devyatkov.

It was found for the biological objects studied:

- the existence of irradiation effects which depend strongly on frequency, sometimes in a resonant manner,
- the existence of a threshold intensity necessary for induction of such effects, and that over an intensity range of several orders of magnitude above the threshold, the induced effects do not vary with intensity,
- the effects are observed to depend on duration of irradiation.

The results obtained are of great scientific and practical interest. For example, it was established that a vital activity of microorganisms is induced by millimetre wave radiation of low intensity.

The effect may be as both positive and negative one, depending on the particular conditions of irradiation and system characteristics. Different systems and many tests were studied, especially cell division under MM radiation. Here some experiments will be outlined.

Smolanskaya and Vilenskaya [2] reported that under MM wave radiation intracellular systems are responsible for lethal synthesis in bacteria, i.e. the synthesis of substances that result in the death of the cell. The colicinogenic (col) factor of E. coli was chosen as the test. The col-factor is an extrachromosomic genetic element. The functional activity of this element is normally repressed, but a number of physical and chemical influences can induce its activity. Under MM radiation the col-factor results in synthesis of a special protein substance known as colicin. The cell then perishes. Colicins are proteins coded in a small extrachromosomal plasmid called the col factor. The colicin...
that it produces has an antibacterial action with respect to other bacteria of the same and similar species.

The activity of the colicin synthesis was determined by the method of lacunas. It was found that the number of colicin-synthesizing cells increased sharply upon irradiation of the colicinogenic strain with millimetre waves of certain wavelengths. Thus, the number of cells that synthesized colicin increased by an average of 300% upon irradiation at wavelengths of 5.8; 6.5 and 7.1 mm. At the same time, neighbouring wavelengths (6.15 and 6.57 mm) showed no such effect. The results obtained were reproduced with high regularity. Thus the effect of E. coli to produce colicin was induced only at particular frequencies.

Smolanskaya and Vilenskaya also studied the influence of the power density of radiation on induction of the colicin synthesis. Variation of the power density by a factor of 100, from 0.01 to 1.00 mW/cm$^2$, had no influence on the induction coefficient, and only a further reduction of power density down to 0.001 mW/cm$^2$ resulted in a sharp decrease in the biological effect (Fig. 1).

That the effect does not depend on power density was a strong argument in favour of the nonthermal effects of millimetre waves, since all thermal effects depend primarily on intensity of irradiation.

The results of the scientific session of the USSR Academy of Science were not pilot results, because beginning around 1965, a number of organizations in the USSR began under the direction of N.D. Devaytkov systematic researches on the effects of low-power millimetre waves on biological objects.

Various yeast cultures were irradiated. A resonant effect of MM-waves irradiation on the division rate of the cells being irradiated was observed. Thus, for example, irradiation of a culture of Rhodotorula rubra at some wavelengths showed a sharp frequency dependence. Irradiation of a Candida culture caused a marked change in the nature of cell division as compared with the control. It was revealed an increase in production of proteases with fibrinolytic activity by the fungus Asp. aryzal, effects of irradiation on staphylococci etc.

It was established for a wide variety of microorganisms and tests that, beginning at a certain threshold power flux density of about 0.01 mW/cm$^2$, the effects vary weakly over several (two and five) orders of magnitude when a marked thermal effect is already beginning to make its appearance.

The scientific session of the USSR Academy of Science was a culmination of several years of research and scientific discussions at the highest level. At this scientific session, specialists working in the fields of biophysics, microbiology, biochemistry, and medicine, were invited. Even some the
most well-wishing scientists have met the report with doubt. These doubts were called by basic characteristics of nonthermal effects of MM radiation:

- Narrow frequency resonance has had the Q-factor, which one in some experiments was suspiciously high.
- Sharp threshold with following plateau on power axis, as in the Smolyanskaya experiment, did not meet to the experimenters earlier.
- In first part of the 20th century they thought that nonthermal effects may be only in the region, where $\hbar \nu >> kT$, and are impossible in region, where $\hbar \nu << kT$, as quantum energies $\hbar \nu$ is essentially insufficient to call any chemical transformations in materials.

The brief contents of some papers were published in Soviet journal “Uspekhi physicheskikh nauk”. It has English translation “Soviet Physics – USPEKHI”, which was published in 1974 [1, 2]. Therefore scientists of other countries could know the soviet results and try to replicate some of them.

Reproducibility of outcomes

Quickly it has been found, that researchers in this discipline have had great difficulty in replicating results obtained by others. And what is more, the same scientists can observed the effect or can not.

The most strange history was with colicin induction by *E. coli*. As noted above, for the first time this effect has been reported by Smolyanskaya and Vilenskaya in 1973. This effect has been confirmed by M.L Swicord, T.W. Athey, F.L. Buchta and B.A. Krop at the 19th General assembly of URSI in Helsinki in 1978 [3]. However, in 1979, at the Bioelectromagnetics Symposium in Seattle Athey T.W. (Bureau of radiological health, USA) reported: “We devoted about a year to the colicin induction experiment. In the pilot study using a temporary experimental system, we seemed to be getting some positive results; but after refining our experimental system we never again saw any increased colicin induction” [4]. In contrast to Athey, at the Seattle Symposium Motzkin S.M. (Polytechnic Institute of New York) reported results in support of the Smolyanskaya and Vilenskaya original observation. She said:

Preliminary observation that W3110Col E1 *E. coli* can be induced to produce colicin by CW irradiation at 37°C for 1hr, at 5.8 mm and a power density of 0.5 mW/cm²[5]

The Bioelectromagnetics Symposium in Seattle on June 22. 1979 [6] was the most serious discussion of this problem. At this symposium L.M. Partlow (University of Utah, USA) remembered in addition, that Hill et al. [7] have been unable to replicate the frequency-specific effects previously reported by Barteaud et al. [8] in 1975 on the rate of growth of *E.coli*. This bacteria is depressed by radiation of 71 and 73 GHz.

Similarly, Baranski et al. [9], Ismailov [10], Melnick [11], Motzkin [12] have all reported that microwave radiation had a nonthermal effect on the permeability of red blood cells (RBC’s). In contrast Liu and Cleary [13], Hamrick and Zinkl [14], Peterson, Partlow and Gandhi [15] have demonstrated that erythrocyte membrane permeability is equally affected by microwave radiation and conventional heating.

In 1978 W. Grundler [16,17] studied the growth behavior of yeast cultures under coherent microwave irradiation. To avoid thermal effects of irradiation he chose to use a yeast cell culture in stirred aqueous suspension, as this assures an efficient thermal exchange between the cells and the surrounding medium. The temperature of the suspension (32±1°C) was continuously monitored. Similar to a yeast experiment described by Devyatkov, frequencies were chosen in a range near 42 GHz. When the cultures were irradiated by CW microwave fields of a few mW/cm² the growth rate either stayed constant or was considerably enhanced or reduced depending on the frequencies varying by no more than a few megahertz in the 42 GHz range. A spectral fine structure with a width of the order of 5-10 MHz was observed. Careful temperature monitoring excludes a trivial thermal origin of this effect.
In 1979 Webb published a paper [18], where the induction of lambda prophages in *E. coli* under irradiation by millimetre microwaves was chosen as the test object. The effect was distinctly frequency-dependent and has dependence on power density at frequency 70.4 GHz. The effect was observed at 35°C after 24 h incubation.

Experiments were conducted at the University of Utah in U.S.A. to obtain nonthermal effects of MM radiation[19–21]. Experiments performed at this University focused on the replication of the experiments reported by Grundler et al [16,17]. The University of Utah team used a more perfect instrumentation. No differences greater than +/- 4% were detected in the growth rates of yeast for any of the 15 frequencies chosen to coincide with the “resonance frequencies” reported by Grundler et al.

In 1991 in Moscow there was the International symposium “Millimeter waves of nonthermal intensity in medicine”. Motzkin S. (USA) has represented the abstract with the title “Low power continuous wave millimetre irradiation falls to produce biological effects in lipid vesicles, mammalian muscle cells and *E. coli”’ [22]. The last words of this abstract were such: “To date we have not observed any statistically significant alteration in *E. coli* proliferation, colicin induction, membrane fluidity or variation in resting potentials or miniature end plate potentials. Available data do not conclusively define low level mm waves as a biological hazard”.

In early 1990s Ziskin and colleagues tried to look for nonthermal frequency-dependent effects of millimeter wave electromagnetic radiation [23]. Similar to the millimeter wave sources used for Soviet experiments, Ziskin and colleagues also used backward-wave oscillators in the frequency bands 37.5-53.57 GHz and 53.57-78.33 GHz, respectively. It was not possible to find out required nonthermal effects.

It was not surprise, that after such numerous negative results the American experimentalists were sure that nonthermal frequency-dependent bioeffects are not in reality and finished researches in this discipline.

But European researches were continued the study, and new interesting results were obtained. In 1996 the effect of millimeter waves on the genome conformational state of *E. coli* AB1157 cells was studied by the method of anomalous viscosity time dependencies in the frequency range of 51.64 – 51.85 GHz and power density in the range from $10^{-19}$ to $3 \times 10^{-3}$ W/cm² [24]. The power density dependence of the MM waves effect at one of these resonance frequencies (51.674 GHz) differed markedly from the corresponding dependence at the 51.755 GHz resonance, the power window occurring in the range from $10^{-16}$ to $10^{-8}$ W/cm². The Fig.2 gives the maximum relative viscosity as a function of logarithm of power density (W/cm²).

In up-to-date practice of scientific publications, it is not done to report about unsuccessful results, but in the case of nonthermal frequently-dependent MM wave bioeffects we have an exception to the rule because one group of experimentalists have shown the lack of nonthermal effects obtained by other group of scientists. The pioneers of nonthermal MM waves bioeffects ignored completely the negative results of American scientists. Furthermore, they developed this discipline in direction of medical uses and introduced the new methods of MM therapy in medical practice of treatment many internal diseases: about 40 in Russia and about 60 in Ukraine [25, 26]. In Moscow new methods of MM therapy are in the list of insurance medicine.
Figure 2. Power density dependence of maximal relative viscosity in cell lysates after *E. coli* cell exposure at the 51.674 GHz. Cell concentration during exposure was $4 \times 10^7$ cells/ml.

The described situation is surprising, because for 40 years the experimenters could not solve it by their forces, despite of a very high level of experimental skill. It means, that the science has met a very great and new problem. In a history of electromagnetic radiation, already there were the striking problems, and all of them were solved by methods of thermodynamics. It is of interest, what is given by thermodynamics for comprehension of non-thermal processes of electromagnetic radiation.

**Thermodynamic methods of the solution of problems of electromagnetic radiation.**

In 19 century efforts of forward physicists were focused on research of the laws of equilibrium thermal radiation. Many theorists attempted to calculate the universal function of G. Kirchhoff $\varepsilon_{\nu,T}$.

The German physicist W. Wien was the first to use the thermodynamic method to find a solution of this problem. He propagated concepts of absolute temperature and entropy to heat radiation. In the total W. Wien formulated two laws which described a short-wave wing of equilibrium heat radiation in good conformity with experiment (W. Wien region). For this discovery, he received the Nobel Prize in 1911. However, the formulas of W. Wien were in a drastic contradiction with outcomes of experimental outcomes for a long-wave wing of heat radiation.

The problem of the theoretical description of the long-wave wing of heat radiation was resolved by Lord Rayleigh on the basis of the laws of classic thermodynamics. Later on his outcome was updated by Jeans. The Rayleigh – Jeans formula is conformed to the realm of radio-frequency radiation and extremely low frequencies (the Rayleigh – Jeans region) But the Rayleigh – Jeans formula was not suit at all for a short-wave part of equilibrium radiation. On memory of this fact, the expression «ultra-violet catastrophe» was coined.

Problem of the theoretical description of the universal function of Kirchhoff $\varepsilon_{\nu,T}$ was completely resolved in ingenious paper of M. Planck, in 1900. While using the thermodynamic method, M. Planck introduced, for the first time, the concept of the quantum of energy and formulated nowadays well-known formula, which gives the full description of the Kirchhoff function $\varepsilon_{\nu,T}$ for any wavelength

$$\varepsilon_{\nu,T} = 2\pi v^3 c^2 \left[ \exp(\nu kT) - 1 \right]^{-1}$$

For this work, M. Planck received the Nobel Prize in 1918.
For the solution of our problems, I believe it is expedient to copy as
\[ c^2 \frac{\epsilon_{\nu,T}}{2 \pi \hbar^3} = [\exp(\hbar \nu / kT) - 1]^{-1} \]  

(2)

In 1905, A. Einstein entered a representation about quantum structure of light (Nobel Prize in 1921). In 1924 S. N. Bose elaborated quantum statistics for particles with the integer spin and, on this basis, received the Planck law for heat radiation. Then the physical sense of the exponent in the Planck formula (2) has become clear. The particles with the integer spin are called bosons.

In the beginning of the 20th century M. Planck [27] wrote the book, in which all aspects of equilibrium radiation are reviewed in details. One of the main concepts of this book is the concept of a flow of entropy of equilibrium radiation \( S \), which is calculated according the following formula
\[ S = 2 \pi k c^2 [\nu^2 \ln(1+\rho) - \rho \ln \rho] \]  

(3)

where \( c \) is the speed of light, \( k \) is the Boltzmann constant, the distribution function \( \rho \) is given by the formula (2) for heat radiation
\[ \rho^* = c^2 \frac{\epsilon_{\nu,T}}{2 \pi \hbar^3} \]  

(2a)

What is the physical sense of this value? It is very simple: the value \( \rho^* \) demonstrates number of photons at a definite level of energy.

Many Russian theoretical physicists are sure of, that the formula for flow of entropy (3) was deduced for the first time by the outstanding Soviet theorist, Nobel prize winner L. Landau. This opinion is a mistaken one, because M Planck had already deduced this formula long before the birth of L. Landau. However, L. Landau has the most direct relation to the formula (3).

The fact is that M. Planck had deduced this formula for equilibrium radiation. Einstein and Bose had also considered a system of equilibrium bosons, and L. Landau showed that the formula (3) is justified for non-equilibrium electromagnetic radiation [28]. In this case \( \rho \) is determined not by the formula (2a), but formula (4)
\[ \rho = c^2 E_\nu/2 \pi \hbar^3 \]  

(4)

in which instead of the Kirchhoff function \( \epsilon_{\nu,T} \) (spectral density of equilibrium heat radiation) is used \( E_\nu \) (spectral density of non-equilibrium electromagnetic radiation). The regularity of Landau’s conclusion was confirmed by Western scientists [29, 30].

This theoretical refinement had a large practical significance in the 20th century and allowed to answer some questions. For example, Landau has made the concluding about a capability of light efficiency greater than unity and capability of optical cooling. His conclusion was so radical and unexpected, that only few theoretical physicists-contemporaries could believe it [31 – 33].

However, experimenters obtained the optical cooling in experiment with different physical samples and systems very successfully. In 1997, the Nobel Prizes on physics were awarded to S. Chu, C. Cohen-Tannoudji and W.D. Phillips for optical cooling by laser light.

What is the relation of the foregoing to the explanation of problems generated by the biological effects of MM radiation? It is a direct one: MM radiation and other electromagnetic radiation are subject to the Bose - Einstein statistics. It means that the flow of entropy of this radiation should be
calculated according to formula (3). The graphic dependence of \( \log S \) on \( \log \rho \) is shown in Fig.3.

![Graph showing \( \log S \) vs \( \log \rho \)](image_url)

**Figure 3.** Logarithm of entropy flux of bosons as function of \( \log \rho \)

For a flow of bosons, the different degree of density of population of energy levels is possible. By a way of a straight submission of numerical characteristics of equilibrium or non-equilibrium radiation of the W. Wien region in the formula (2a) and (4) it was received, that for this realm the condition \( \rho << 1 \) is realized.

The calculation for the Rayleigh-Jeans region gives other ratio \( \rho >> 1 \). The bosons, which are submitted to the condition \( \rho >> 1 \), are called as the Bose condensate because the large number of quanta is condensate at the lowest level. The Bose condensate in Fig. 3 is shown by the dot-and-dash line.

For a better visualization of a situation it is possible to give Tab.1. In Tab.1, the outcomes of concrete direct calculation of number of photons of equilibrium radiation at one level \( \rho^* \) are given at room temperature (300 K) and at the temperature of Sun radiation (5800 K).

**Table 1.** \( \rho^* \) as a function of frequency \( \nu \) for two temperatures (300K and 5800K) of equilibrium radiation

| \( \nu \) | \( 10^{10} \) | \( 4.6 \times 10^{15} \) | \( 10^{21} \) | \( 4.3 \times 10^{22} \) | \( 10^{29} \) | \( 5 \times 10^{33} \) | \( 10^{41} \) |
|---|---|---|---|---|---|---|---|
| \( \rho^* \) | 625 | 135 | 62 | 6 | 1 | 0.25 | \( 3 \times 10^{-3} \) |

| \( \nu \) | \( 10^{15} \) | \( 4.6 \times 10^{18} \) | \( 10^{33} \) | \( 10^{37} \) | \( 5 \times 10^{40} \) | \( 9 \times 10^{43} \) | \( 5 \times 10^{49} \) | \( 9.5 \times 10^{44} \) |
|---|---|---|---|---|---|---|---|---|
| \( \rho^* \) | 12500 | 2610 | 1204 | 120 | 1.9 | 1 | \( 1.6 \times 10^{-2} \) | \( 4 \times 10^{-4} \) |
In this table two frequencies are selected. One characterizes frequency, at which $\rho^* = 1$, and the second frequency $4.6 \times 10^{10}$ Hz is a frequency of maximum of colicine induction by E. coli in experiment of Smolyanskaya and Vilenskaya [2]. The values $\rho^*$ equal to 1, or close to 1, are in the infrared range. At room temperature, in equilibrium radiation on frequency $4.6 \times 10^{10}$ Hz there are 135 quanta of MM radiation. The intensity of non-equilibrium MM radiation is always higher than equilibrium intensity. The calculation for the Smolyanskaya and Vilenskaya experiment demonstrates, that $\rho^*$ in conditions of a beginning of a reversible effect (threshold) is equal to 1100. We shall discuss these in the following section.

At this point, it is useful to recollect the problem $kT$. As is evident from the foregoing, such a problem simply does not exist for living systems, which exist at room temperature or close to room temperatures. At these temperatures the presence at a level of energy only one quantum of MM radiation is impossible. There are always many, as a matter of fact, lots of them. The ensemble of bosons is very large. One quantum of MM radiation at a level of energy can be received only at a very low temperature. I shall not calculate it, because life does not exist at such low temperature. All foregoing can call bewilderment of the reader, because the concept of Bose condensate in our representation is uniquely connected to the superconductivity of metals and not related to living systems.

This paradox has appeared as follows. When the superconductivity of metals was discovered in experiment at the beginning of the 20th century, the theorists could not find explanation for this phenomenon very long. Metals are subject to the Fermi-Dirac distribution, which forbids presence at one level more than one electron ($\rho < 1$). But for explanation of superconductivity it was necessary to admit $\rho > 1$.

At first, this phenomenon was called as Fermi degeneration and only later investigators understood, that at very low temperatures, the system changes the statistics and passes over from the Fermi–Dirac distribution to the Bose-Einstein distribution, which enables the presence of many electrons on the lower layer, i.e. Bose condensation. The problem of superconductivity was such widely discussed in the 20th century, that the impression was added up for many, that the Bose condensate is by all means metal in conditions of the lowest cooling. Only after obtaining the Nobel Prize in 2003, sensation around of the Bose condensate in metals was abated.

On arena of strife for the Nobel Prizes other exotic phenomenon has appeared. It is Bose condensation of excitons. The exotic phenomena draw away scientific attention from ambient life. Between that, how it is obvious from the foregoing, radio-frequency radiation and extremely low frequencies (the Rayleigh–Jeans region) are the Bose condensate of electromagnetic radiation. The radiation of the Wien region is not such.

While great physicists struggle for Nobel Prize, they do not have time to look on ambient life and to inform ordinary physicists and population of the planet, that they live in Bose condensate of man-made radio-frequency electromagnetic radiation. Its intensity rises permanently as an index of technical advance. Now it is not known, than it threatens to mankind and other forms of life in nature.

At our life there is no understanding that all of us live in a field of the Bose condensate. In these conditions is not surprising almost, that scientific investigating of bioeffects of MM radiation and other radio-frequency radiation, has not had any right direction, and almost 40 years, scientists attempted to troubleshoot, which actually does not exist.

The paradoxical situation with the problem $kT$ in nonthermal effects of MM radiation resembles very much the situation of the hero in a play of the French comedy-writer Moliere. This hero has said: «But I did not know, that I speak prose!» Now each one of us can say: “I did not know, that I live in the sea of the Bose condensate of radio-frequency electromagnetic radiation.”
Thermodynamic consideration of biomedical effects of MM electromagnetic radiation

In second half of the 20th century as prolongation of activities of M. Planck \[27\], L. Landau \[28\] and M.A. Weinstein \[31\] the thermodynamic theory of isothermal conversion of energy of electromagnetic radiation in open systems was considered. Fig. 4 shows the system under consideration, which has been described in many journal publications and books of Chukova \[34–46\] and Landsberg & Tonge \[33\]. Here are represented the following: energy flow and entropy flow of the absorbed electromagnetic radiation ($\dot{W}_a$ and $\dot{S}_a$) and reemission ($\dot{W}_L$ and $\dot{S}_L$), similar characteristics of reactants ($\dot{U}_r$ and $\dot{S}_r$) and products ($\dot{U}_p$ and $\dot{S}_p$) and heat flow ($\dot{Q}$ and $\dot{Q}/T$). $\dot{S}_I$ is energy generation rate due to irreversibility of process.

This system was utilized for explanation of outcomes of rather different experiments. Now conversion of energy of electromagnetic radio-frequency radiation (mainly MM radiation) into the energy of chemical bonds (into the Helmholtz free energy) is the main interest for us. This efficiency $\eta$ is calculated according to the formula

$$\eta = 1 - T (\dot{S}_a + \dot{S}_I)/\dot{W}_a$$

(5)

which is obtained on the basis of the energy conservation law and the equation of entropy balance in the stationary state of a system without any individual suppositions. Therefore this formula is of a very general nature. It has already been reviewed in detail in many previous publications. For this reason, only the total outcome will be shown here.

Fig. 5 shows the full scale of electromagnetic frequencies, which are now investigated in biomedical experiments. The Wien region and the Rayleigh–Jeans region and between them - IR (infrared) radiation are represented. The ratio of quantum of thermal oscillations $kT$ and quantum of electromagnetic radiations $h\nu$ are given, as well as is the ranges of $\nu$. On the lowest part, are shown the representative dependence of efficiency $\eta^*$ of reversible conversion of electromagnetic radiation energy into the Helmholtz free energy on log of spectral density of absorbed radiation $E_\nu$.
Both figures are given to the semilogarithmic scale: the abscissa axis is the log of spectral density of electromagnetic radiation, and the ordinate is the thermodynamic-limit efficiency $\eta^*$. In the Wien region we see the well-known logarithmic relation (the Weber–Fechner law), and in the left-hand part we see the step, which was observed by the Soviet scientists. Thus, the relation, obtained by the Soviet scientist, the step-dependence on absorbed energy is not surprising at all: it is dictated by the laws of physics. More precisely, it occurs as a consequent of quite definite dependence of a flow of entropy of electromagnetic radiation on the spectral density of absorbed energy.

In Fig. 3 it is evidence, that the entropy of a flow of bosons increases variously depending on $\rho$. There are two regions: $\rho < < 1$ for the Wien region and $\rho > > 1$ for the Rayleigh–Jeans region (the Bose condensate region). This difference determines essentially different efficiency of conversion of energy of electromagnetic radiation in the Wien region and in the Rayleigh–Jeans region. Thus, the second problem of bioeffects of MM radiation actually is not a problem.

Now concerning the high Q-factor of bio-resonant effects of MM radiation: there is no problem, because the main cause of broadening of absorption (or radiation) line is the energy dissipation on phonons. But this process is possible only for the Wien region and there is no place in the Rayleigh–Jeans region. The outstanding American theorist C. Kittel paid special attention to these in his fine book [47].

**REGION OF ELECTROMAGNETIC WAVES (Hz)**

| $10^1$ | $10^2$ | $10^3$ | $10^4$ | $10^5$ | $10^6$ | $10^7$ | $10^8$ | $10^9$ | $10^{10}$ | $10^{11}$ | $10^{12}$ | $10^{13}$ | $10^{14}$ | $10^{15}$ | $10^{16}$ | $10^{17}$ | $10^{18}$ | $10^{19}$ | $10^{20}$ | $10^{21}$ | $10^{22}$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| IR    |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| The Rayleigh–Jeans region | The W. Wien region |
| $kT \gg h\nu$ | $kT << h\nu$ |
| $\rho >> 1$ | $\rho << 1$ |

**Figure 5.** Outline of main characteristics of electromagnetic radiation

Nevertheless, there is a question: «Why do the outcomes of biomedical effects of MM radiation have a surprising poor reproducibility?» The answer was given a long time ago, and it is simple. In living systems under MM radiation there are processes, which can flow in a direction of increase of the Helmholtz free energy (endergonic processes) or in a direction of decrease (exergonic processes). Nowadays studied effects of MM radiation are endergonic processes [38 - 45]. The position of boundary between them for the reversible process depends on frequency and spectral density of absorbed radiation. This boundary is shown in Fig. 6. Here the light field is an area of
endergonic processes, and the area of exergonic processes is hatched (shaded). Only some exergonic processes have been studied to present time [48 – 51].

\[
\dot{S}_i = \alpha W_a + \beta W_a^n
\]  \hspace{1cm} (6)

The linear increase \( \dot{S}_i \) gives the shift \( \eta^* \) along the axis of absorbed energy. For already above mentioned synthesis of colicine in E. coli, this shift is submitted in Fig. 7. Here \( \eta^* \) is thermodynamic limit efficiency, the points are experimental data of Smolyanskaya and Vilenskaya, \( \eta \) is real efficiency, obtained by thermodynamic method.

Here it is useful to recollect the already mentioned large value of number of bosons at a level of energy in this classic experiment. If this process is reversible, in point of the threshold of effect the number of bosons would be about 1100. At the point of actual threshold of process of colicine synthesis the number of photons are \( 2 \times 10^7 \). In the last experimental point the number of photons are \( 2 \times 10^{10} \).

Such linear irreversibility of processes under the Rayleigh - Jeans radiation is characteristic for all investigated processes.

The main cause of poor reproducibility of bioresonant effects is connected with the sharp dependence of efficiency on absorption of energy near the point of a threshold of effect. The smallest change of value of absorption is capable to change the sign of effect: endergonic process passes in exergonic or vice versa. In this situation a procedure of averaging, which is used by the experimenters in biological experiments, easily can result in zero outcome. In experiments with microorganisms, where there is an automatic averaging on an ensemble, only an experimenter of the

**Figure 6.** The regions of exergonic processes (hatched area) and endergonic ones (light area) for conditions of thermodynamic reversibility.
highest proficiency does not lose the effect, and the experimenters of lower proficiency lose it, even if it was seen in the pioneer experiments.

Figure 7. Efficiency of colicine synthesis in E. coli for reversible ($\eta^*$) and for irreversible real processes ($\eta$)

In medical practice the reproducibility of outcomes is higher, than in biological experiments because the doctor works with the separate patient, and the procedure of averaging is eliminated.

The second cause of poor reproducibility of outcomes is that entropy generation rate in a system is non constant. It changes depending on many factors such as age of individual, satisfied or hungry individual, the concentration of different chemical agents in medium, where he/she is and others. Therefore, in the same system the outcome is not always reproduced. The third and last cause is connected to superlinear increase of entropy generation rate at strong absorption of energy. Sometimes, the experimenters increase the absorption, hoping to increase effect. But they reach opposite outcome. At high absorption and strong deviation of a system from equilibrium, the endergonic processes decrease and their efficiency reaches zero point. These have been reviewed in details [41 - 45, 53].

The Soviet pioneers-scientists were successful because they could find some living systems with rather low linear irreversibility and very low superlinear irreversibility.

Conclusion
Thermodynamics does not prohibit isothermal processes in conditions $h\nu \ll kT$ (the Rayleigh-Jeans region), but thermodynamics asserts, that such processes have the characteristics much distinct from those, which have been studied by experimenters up to 1973. For the first time these characteristics were discovered by the Soviet scientists under leadership of Acad. Devyatkov.

For successful studying of biomedical processes under the Rayleigh-Jeans radiation ($h\nu \ll kT$), it is necessary another planning an experiment and other handling of data processing. The generally accepted norm of averaging of outcomes is extremely unwanted in the Rayleigh-Jeans region, because in conditions of sharp transition from exergonic process to endergonic process at very small change of absorption, microbiological ensembles will give zero total outcome with high probability. Therefore at the 20 century the medical effects of radio-frequency influence has been fixed easier, than microbiological one. It has as result a broad development of MM - therapy in
a number of countries, while the number of accurate and stringent physical experiments is rather limited up to the present.

References

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