Research Article

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Torsional Vibrations of DNA and RNA

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ABSTRACT

Experimental evidence of suppression of bacterial survival at resonant frequencies is given, it is indicated that centimeter waves can cause hormesis. It is shown that the torsional rigidity of DNA or RNA helices in the free and in the compactified state differs by 30 orders of magnitude. Exact formulas for the natural frequencies of torsional vibrations of DNA and RNA are obtained. The confirmations of the theory according to which the natural frequencies of torsional vibrations of DNA helices are located in the centimeter spectrum are indicated.

Keywords

Spiral, Resonance, Bacteria, Viruses, Subharmonics, Rigidity.

Introduction

Electromagnetic radiation of excited DNA molecules and absorption are observed in the UV and IR spectra. The Frank-Kamenetsky group in 1974 determined that excited DNA molecules also emit in the centimeter (ultrahigh frequency, microwave) range, and this radiation is due to torsional vibrations of DNA as a whole [1]. Bingi also pointed out that during torsional vibrations of the DNA molecule as a whole, microwave radiation occurs [2]. Thus, the microwave does not emit any short sections of DNA, not genes, but a DNA molecule as a whole. It is not electrons with protons that oscillate, but dipoles A-T and G-C along the DNA helix. Mathematical modeling shows that the natural frequencies of short sections of DNA lie in the range of terahertz (see below), and the experiment shows the same [3].

In [4], data were obtained on a decrease in the survival rate of E. coli under the influence of microwave, namely: the dependence of survival on the time of irradiation at different frequencies. It turned out that if we recalculate the data for frequency dependence, it is clear that the resulting curve has a distinctly resonant character, and it is not difficult to determine the resonant frequency for this type of E. coli – 10.14 GHz from this curve. From the classical Newton equations (using Lagrangian formalism), a formula for torsional oscillations of DNA helices was obtained

$$f = kN^{-1/2} \qquad (1)$$

where N is the number of nucleotide pairs in the DNA helix, k is the empirical coefficient [5]. Using the data [4], we obtained a numerical value of the coefficient, which integrally takes into account the compactification of DNA, its environment (friction), the content of water molecules in the large and small grooves along the DNA helix, which are periodically squeezed out of the warts and filled in again, etc. Experiment and analysis show that the effect of friction is negligible.

It turns out that the frequency of torsional vibrations does not depend on whether even a short spring is annular or linear. The initial model is 2 discs at the ends of the spring, spinning in opposite directions, i.e. the center of the spring is stationary, the halves of the spring oscillate. Further, the mass of each disk is identified with the mass of half of the spring. Hence the formula [1] is obtained. We will move both disks to the center and fix the ends of the spring. The vibrations are made again by the halves of the spring, but the nature of the vibrations is different: from antisymmetric vibrations become symmetrical, i.e. for bacterial ring DNA and linear – the same formula [1]. Why was the Schrodinger equation not needed? Because the length of the DNA helix in bacteria is millimeters, in humans DNA lengths range from 3 to 8 centimeters, these are macroscopic objects, so their fluctuations are described by classical, not quantum equations.

Experimental Evidence of Resonance

Hormesis

Using formula (1), a resonant frequency was obtained for the DNA of another strain of *E. coli*, ATCC 25922, containing 5,130,767 nucleotide pairs - 9.6 GHz. The experiment shows that irradiation of the culture of this strain causes a decrease in the survival rate of bacteria by 80% compared to the control, while there is no effect at all other frequencies [5]. In the same way, resonant frequencies were obtained for longer DNA of M. Avium and Micobacterium tuberculosis bacteria (Koch sticks). The nucleotide sequence of chromosomal DNA of the laboratory strain M. avium 104 (subsp. hominissuis) of this DNA molecule is 9.3 GHz. The cycle of cell division is 1 hour.

The DNA length of the standard pathogenic MBT H37Rv is 4,411,529 base pairs, the resonant frequency of torsional vibrations of DNA is 10.36 GHz. The division cycle is 14-18 hours. In all experiments, a non-thermal power flux density of 2.5 mW/cm^2 was used. Irradiation of cultures of these bacteria with an electromagnetic field showed a decrease in the survival rate of M. Avium to zero and a thousandfold decrease in the survival rate of Koch's bacillus in comparison with the control [6,7]. Curiously, for a sharp decrease in survival, it is necessary to irradiate bacteria for 6 cell cycles, that is, E. coli culture – 3 hours, M. Avium – 6 hours, Koch stick culture - 104 hours. It turned out that after irradiation during the first cell cycle, the opposite effect occurs, hormesis, a jump in survival by almost 100%. After the third cell cycle, survival returns to the previous level [7].

The rigidity of the DNA helix

It would seem that with a spiral thickness of several atoms, its rigidity should be extremely small, so the excitation from one section of the spiral to another should be transmitted with huge losses. But due to the fact that the DNA chain has several levels of compactification, it is actually twisted into a point, so its rigidity is high enough to transmit excitation as in a conventional spring. Which corresponds to the formula (1). Indeed, as the experiment showed, the DNA molecule behaves like an elastic rod when twisting [6], it was the elastic rod model that was used as the basis for calculating formula (1). We show that the torsional stiffness almost does not depend on the length of the DNA. Let's also determine how much DNA compactification changes the torsional rigidity of its helix. To do this, we will use numerical experiments with DNA of a random nucleotide sequence of various lengths from 15 to 35 nucleotide pairs. Van der Waals, electrostatic, torsion potentials of standard rotation angles and the presence of hydrogen bonds were taken into account. The model of double-stranded DNA stretched by the ends of 5' with a total force of 10 pN stretched within 20% [7].

From here it is easy to get an approximate Young's modulus (stiffness coefficient) - $3 \cdot 10^{-4}$ N / m, and an approximate resonant frequency for the model – 4 GHz. You can calculate the Young 's modulus for DNA of any length by the formula

$$E_i = El_0 / l_i \qquad (2)$$

The frequency of longitudinal vibrations of the spring

$$f = \frac{1}{2\pi}\sqrt{E/m}$$

Denote the number of nucleotide pairs in the model chain N_0 ; e Young's modulus E_0 . Denote the number of nucleotide pairs in the model N_0 , the rigidity of the i-th chain is E_i . General formula

$$f_i = \sqrt{E_0 N_0 / 2m_0} / \pi N_i$$

where m_0 is the mass of the DNA base pair, N_i is the number of base pairs for the i–th type of DNA. For *E. coli* with a chain length of 5 million base pairs, the resonant frequency will be about 10^4 Hz. The frequency of human DNA is 2 orders of magnitude lower. For fibrils with 50 – 200 thousand base pairs attached to the nuclear matrix, taking into account histone inclusions, the frequency will be in the long-wave range – about hundreds of kilohertz.

The torsional stiffness G is expressed in terms of the shear modulus

$$G = \zeta \pi r^4 / 2l \qquad (3)$$

From the fact that the shear modulus is proportional to Young's modulus and from formulas (2) and (3) it follows that the torsional stiffness also depends on the length of the DNA. But this dependence is very weak for bacterial DNA, for example, for different E. coli with a DNA length of 4.6 million bp and with a DNA length of 4.5 million bp. The difference in resonant frequencies is determined by the coefficient

$\sqrt{N_1 / N_2} = \sqrt{4,5/4,6} = 0,9945 \approx 1$, that is, the torsional stiffness is almost the same with a high degree of accuracy.

The shear modulus is related to the Young 's modulus as follows: $\zeta = E / 2(1+\nu); \nu$ - Poisson's ratio.

The Poisson's ratio is the ratio of the relative transverse compression to the relative longitudinal tension, it does not depend on the size of the body and is determined by the nature of the material. The Poisson's ratio for concrete is 0.16–0.18, for alloy steel - 0.25–0.30, for aluminum stretched wire - 0.32–0.36, for celluloid - 0.33–0.38, for rubber - 0.47, i.e. does not exceed the limits of the interval (0.1 – 0.5). For *E. coli* DNA with a length of about 106 nucleotide pairs and a length of about 10^{-4} m

$$G = E\pi r^4 / 4l(1+\nu) \sim 10^{-40}$$

Such is the torsional rigidity for a thin linear DNA helix.

Since for the ring the moment of inertia $J = m_{cirle} r^2$, then from formula (1) we get:

$$f = \frac{1}{2\pi}\sqrt{\frac{2G}{J}} = \frac{1}{2}\sqrt{\frac{2G}{Nm_{circle}r^2}} = \frac{21,75}{\sqrt{N}}10^{12}$$

Considering that the diameter of the DNA coil is 2 nm = 2 x 10^{-9} m, the step size of the helix = 3.4 nm = 3.4 x 10^{-9} m. The mass of one average base pair $m_0 = (m_{AT} + m_{GTz})/2$ is 650 daltons (1 Da = weight of a hydrogen atom – $1{,}67 \cdot 10^{-24}$ g). There are 10.5 base pairs per turn of the spiral, we can estimate the order of magnitude of G:

$$G = 0{,}914 \cdot 10^{28} m_{circle} r^2 \sim 10^{-10}$$

That is, the torsional rigidity of compactified DNA is 30 orders of magnitude greater than the torsional rigidity linear DNA.

It would seem that radio waves in the kilohertz range or ultra-long waves can excite longitudinal vibrations in human DNA. However, we are talking exclusively about linear DNA, for compactified DNA of both bacteria and humans, the frequencies of longitudinal oscillations lie in the ultraviolet range.

Direct Experiment

The DNA helix is an inductance, the calculation shows that its resonant frequency is many orders of magnitude higher than the frequency of gamma quanta. All other molecules, anions and cations contained in the shell and inside bacteria, and various organelles cannot react to centimeter waves. Thus, the rotational-vibrational spectra of cellular macromolecules are located outside the microwave range, in the UV and IR regions, the same spectra of the NH_4^+ cation or $H_2P0_4^-$, $HP0_4^{2-}$, $HC0_3^-$, NO_3^{2-} , SO_4^{2-} contained in the cell are also in the terahertz and IR regions, see [8]. For water molecules in a bacterial cell, there is a dedicated resonant frequency of 2.4 GHz, resonance occurs on clusters. Other frequencies in the microwave range are not absorbed by water. In *E. coli* , the plasmid contains 6.6 thousand base pairs, respectively, the frequency is 295 GHz. Thus, there is nothing else in a living cell to respond to centimeter-range waves, except DNA. The longitudinal vibrations of the DNA helix lie in the region of megahertz. However, all of these experiments are quite evidential, but still indirect. In order to conduct a direct experiment, the absorption spectrum of microwave EMF by a culture of *E. coli* M17 bacteria was removed. It was found that the maximum absorption is at a frequency equal to the natural frequency of torsional vibrations of bacterial DNA [9,10]. Resonance was also detected at the calculated frequencies when M. Avium and Koch's rod cultures were irradiated. Thus, for accurate calculations of the frequencies of various DNA, the DNA length of E. coli M17 at 4,483,110 bp can be used as a reference:

$$f_i = f_{i0}\sqrt{N_{M17}/N_i} = 21{,}724\sqrt{N_{M17}/N_i^2} \quad (4)$$

There are no obstacles to go beyond the test tube and apply microwave EMF to inhibit pathogenic bacteria in the body. Centimeter waves, like mobile communication waves, freely pass through the human body.

In phthisiology, with cm and dm therapy, the depth of penetration of waves into the body is 12-15 cm, but this is a warming therapy, that is, the density of the radiation power flux is high. In heated tissues, a skin effect occurs, which inhibits electromagnetic waves. If the power flow density is low, there is no heating of the tissues, the skin effect does not occur. Blood is a conductor, but at low frequencies, at the same time it passes centimeter waves, because at ultrahigh frequencies it behaves like a dielectric. Like mobile communications, centimeter waves are absolutely harmless to humans, they pass through their body, lingering exclusively on the DNA of pathogenic bacteria.

Short Spiral Molecules

The frequencies of the intrinsic torsional vibrations of short molecules are hundreds of gigahertz. The higher the frequency, the less penetration into the body, millimeter waves barely overcome the skin, the depth of penetration is about 5 mm. However, to excite resonance in short DNA or RNA, frequencies that are multiples of hundreds of gigahertz can be used. For example, if the natural frequency of the RNA helix is 120 Hz, it is possible to irradiate this RNA with an electromagnetic field of a frequency of 12 GHz, that is, with waves of the centimeter range that freely pass through the human body.

The RNA chains of viruses can be single, they have non-spiral sections, hairpins and other formations. The effect of EMF on RNA twists non-helical sections of the chain into a spiral, i.e. formula (1) is also valid for single RNAs. However, the base in RNA, complementary to adenine, is not thymine with a mass of 126.11334 g/mol, as in DNA, but uracil with a mass of 112.08676 g/mol. Therefore, for single P NC formula (1) changes:

$$f_{ÐÍ\,Ê} = 31{,}159\sqrt{N_{M17}}/N \quad (5)$$

where N is the number of bases (not pairs). For double helix RNA, the coefficient is different, 22.0325, and N is the number of nucleotide pairs.

To check whether the mechanism of resonance excitation works in short DNA molecules, and *in vivo*. The effects of microwave EMF on some arthropod species have been investigated. In arthropod hemolymph amoebocytes, cells similar to human blood lymphocytes, the DNA size is 154,352 nucleotide pairs, the resonant frequency of torsional oscillations of the DNA helix from (4) is 298 GHz. The higher the frequency, the less penetration into the body, waves with frequencies of hundreds of gigahertz penetrate the body to a depth of about 5 mm. But, since for forced oscillations, the frequency of the driving force can be a multiple of the oscillator's own oscillations, it is possible to reduce the frequencies to a range of tens of gigahertz. The multiple frequency is 298: 37 = 8.054 GHz. Marble cockroaches *Nauphoeta cinerea* and encephalitic mites *Dermacentor silvarum* were selected as experimental subjects. It turned out that exposure to an electromagnetic field with frequencies of 7.5 GHz, 9 GHz and 10 GHz did not cause any effect, 8 GHz, 8.1 GHz caused a slowdown in the growth of marble cockroaches and a decrease in the mobility of encephalitic ticks. The estimated frequency of 8.054 GHz caused 100% death of both marble cockroaches and encephalitic ticks [11].

Why did a small deviation from 8.1 GHz cause a strong difference in impact? A small frequency deviation turns out to be significant, because it is multiplied by a multiplicity of 37. If a deviation of 0.5% is significant for DNA with a resonant frequency of about 10 GHz, then in this case the deviation is 0.054 x 37 = 1.998 GHz, that is, about 0.7% of 298 GHz. Using subharmonic resonance, it is possible to achieve the destruction of COVID-19 RNA *in vitro* [12-14]. The length of COVID-19 RNA and 29902 nucleotides. Of (5), the natural frequency of torsional vibrations of RNA is 2,20634 THz, the possible multiplicity is 200. A more effective method is pulse action. Mathematical modeling with Matlab at the ratio of the frequencies of the driving force and its own 1/10, shows that already at the 4th pulse the amplitude of the oscillations doubles:

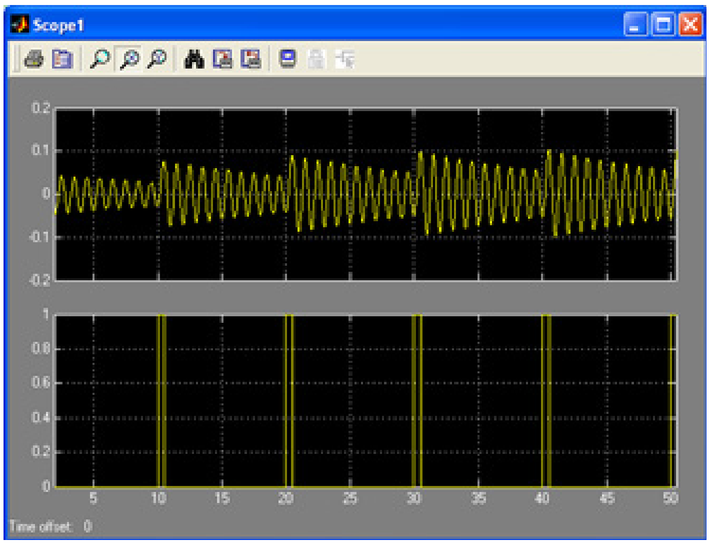

Figure 1: Virtual oscilloscope. The dependence of the oscillation amplitude on time.

The greatest effect is achieved with the waveform in the form of an alternating meander:

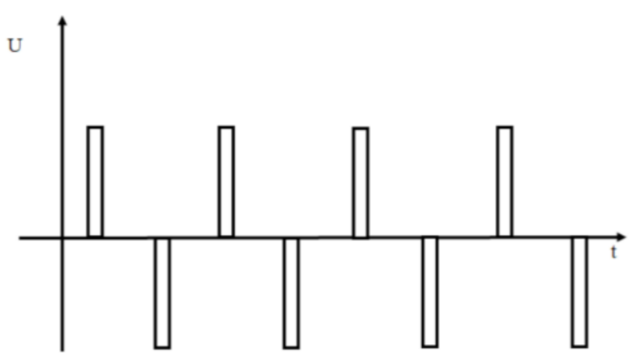

Figure 2: Dependence of the voltage at the output of the microwave generator on time.

What are the mechanisms of action of microwave EMF on spiral macromolecules? Firstly, if ultra-high-frequency torsional oscillations occur in the DNA interphase, this does not allow the replication process to begin (S-phase), and the bacterial cell dies. In principle, we can propose a phenomenological differential equation (the Riccati equation) that describes the torsional oscillations of human DNA with about a million rotating replication forks and the movement of polymerase in the opposite direction, the natural frequency decreases in this [15]. Secondly, the excitation of ultrahigh-frequency oscillations of DNA or RNA helices leads to an increase in the number of single-strand breaks. Thirdly, resonant microwave EMF reduces the ability of DNA to self-repair.

Objections

Reports on the concerted efforts of two independent laboratories [16], which included measuring the dielectric properties of aqueous solutions of ring DNA molecules in the frequency range 1-10 GHz. No resonance absorption or any form of enhanced absorption has been demonstrated. The data are doubtful, since in [1] it was the aqueous solutions of ring DNA that were studied, and it was found that DNA molecules excited by a picosecond laser emit at a frequency of several gigahertz. In addition, more recent studies [4] have shown resonant absorption of E. coli with ring DNA in the region of 10 GHz.

In [17], the study of plasmid DNA also revealed no resonant absorption in the range from 5 to 20 GHz. However, firstly, the natural frequencies of torsional vibrations of DNA helices depend on the length of the ring DNA, which is very different in different bacteria. For example, for *E. coli M17*, *E.Coli hcr' exr'*, for mycobacteria this frequency is higher than 10 GHz, for E. coli ATCC 25922 this frequency is 9.6 GHz. The corresponding frequencies of plasmid DNA are located in the terahertz range, that is, far from the studied range. There is also doubt whether torsional fluctuations of DNA are possible at the time of its replication. However, mathematical modeling shows the possibility of torsional oscillations of the soliton type spreading along the DNA helix [18].

Confirmations

1) In 2009, Malinetskaya's group built a model for 400 pairs of nucleotides [19], the result of machine counting coincided with the result of calculation according to formula (4) – about 100 THz.
2) It was shown that irradiation of E. coli culture leads to a sharp decrease in the ability of DNA to self-repair [20]. It turned out that the frequency of the external EMF exactly coincides with the calculation according to formula (1).
3) It was found that the microwave dramatically increases the number of single-strand breaks [21], mathematical modeling showed that the optimal frequency coincides with the calculation according to formula (1).
4) It has been found that with the help of microwave it is possible to destroy flu strains. It turns out that the resonant frequency found in [22] is a subharmonic consistent with formula (1).
5) In 6 experiments with positive COVID-19 samples at an irradiation time of 30 min, a power flux density of 2.5 MW/cm^2 at frequencies corresponding to the subharmonics of the virus RNA, namely 11.0317 GHz, PCR test showed a negative result, in 8 experiments with frequencies not equal to subharmonics, the PCR test showed a positive result [23].

Conclusion

This method can be used 1) to determine difficult-to-diagnose bacterial diseases, 2) since microwave EMF does not cause mutations - to increase the effectiveness of antibiotics used in bacterial diseases, 3) as an aid in the treatment of viral diseases.

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