Theoretical Analysis of the Basic Effects of Static Electric Field on Biological Tissues

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Abstract: - In this study, the effect of static fields on biological tissues was investigated. Static fields are the fields created by static and inert electric charges. There is little laboratory study or epidemiological evidence of the link between static fields and health damage. In the study of routine exposures to static fields, the study of the magnetic field is generally accepted. The finite membrane potential of the living cell; Because of its high polarizability, significant forces act on the membrane. In addition, the dielectric responses are nonlinear and affect the cell's metabolic states. In a static area that is thought to be harmless; If the biological tissue is mobile, induction currents are likely to occur in the tissue.

Key-Words: Static Electric Field, Biological Tissue, Theoretical Analysis

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1 Introduction

Natural and many artificial sources radiate electromagnetic energy as electromagnetic waves. These waves consist of electrical and magnetic vibration fields. These vibrating fields; It affects biological systems such as plant, animal and human cells in various ways. electromagnetic wave; characterized by wavelength, frequency, or energy. These three parameters are interrelated. In addition, each parameter can be effective on the biological system on its own or together [1].

Some types of electric and magnetic fields support the functionality and adaptability of the cell and organism. These electric and magnetic field forces play an equal role with the most important molecules in the cell such as DNA, proteins and lipids. Living things interact not only with static fields, but also with electromagnetic fields varying at various frequencies. The biological response to exposure is diverse and depends on the organism, tissue, molecular composition of the cell, as well as the parameters of the electromagnetic field (frequency, intensity, modulation, polarization, pulse mode, instantaneous and average power, total energy absorbed, etc.) [2]

Electromagnetic fields have two types of effects. Short-term effects and long-term effects. Effects occurring in a short time; headaches, eye burning, fatigue, weakness, dizziness, nighttime sleeplessness. What can occur in a long time is the effects of electromagnetic fields on molecular and chemical bonds, cell structure, and body protection system [3,4].

It has been found that it deactivates the defense mechanism that prevents harmful proteins and toxins in the blood from entering the brain, causes fatigue, headache, burning sensation in the skin, high blood pressure, headaches, dizziness and distraction. Cell phones increase the risk of neurological diseases such as Alzheimer's, Parkinson's and multiple sclerosis (MS) [5].

Electric fields consist of many natural/artificial sources and play an important role in our lives. Static electric fields exist naturally in the atmosphere and can also be produced through friction. We are constantly exposed to static electric fields in our daily lives due to rail systems and monitors or TVs containing unidirectional currents and cathode ray tubes [6–7]. It has been stated in some experimental and epidemiological studies that the interaction of these areas with biological tissues has some negative consequences [8-9].

Exposure to low-intensity EM fields; It is effective on the synthesis of bio molecules (DNA, RNA and protein), cell division, cancer formation, changes in cell surface properties, calcium entry-exit and binding from the membrane.

It has been observed that hormones are affected in cells and tissues biochemically and physiologically, the hormonal response of tissues and cells changes, carbohydrate, nucleic acid and protein metabolism changes, structural changes are observed, and immune response against different antigens is affected [10].

2 Static Electric Field

Static electric fields are fields created by static and inert electric charges. There is little laboratory study or epidemiological evidence of the link between static electric fields and health damage. While searching for the link between static fields and cancer, only the magnetic field component is seen as a threat to health.

Regarding the mechanisms of the effects of high electric field exposure on animals, there may be two chances: one is a possible effect on organs due to the electric current induced in the body, and the other is effects due to the electric field propagating to the body surface [11].

3 Theoretical Theory of Exposed Field

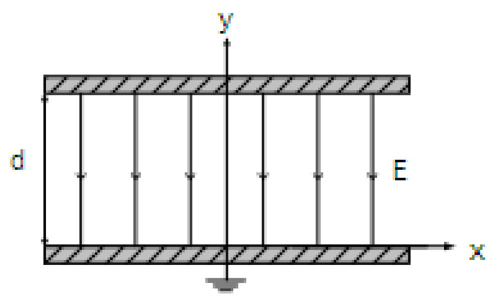

Fig. 1. Arranged parallel plate experiment setup

Figure 1 shows the geometry of the measuring setup. From basic electronic theories; electric field lines are from one plate to another. If corner effects are neglected, this area between the plates is quite smooth [12].

The limit values and electric field intensity levels determined in the guideline published by the International Committee for the Protection of Non-Ionizing Radiation (ICNIRP) were used as the main reference for the experimental setup. Reference has been made to the work carried out by Polk for linear dielectric constant calculations. All measurements, calculations, analysis and design of the experimental setup were carried out at the Electrical and Electronics Engineering Research Laboratory of Suleyman Demirel University. The electric field setup was performed by parallel plate capacitors based on basic electromagnetics, also known as ”parallel plate setup".

$E=\left(\frac{V_0}{d}\right)y=$ constant and vertical lines of force

$U=\left(\frac{V_0}{d}\right)x=$ constant.

A set electric potential value of V;

$$E=\left(\frac{V_0}{d}\right)y \qquad (1)$$

This gives rise to the $W(z)$ function.

$$W(z)=U+jV=\frac{V_0}{d}(x+jy)=\frac{V_0}{d}z \qquad (2)$$

Whether dielectric or conductive; is the electric potential in a general medium, while the electric field is E and is given as follows.

$$\left.\begin{aligned} V&=\frac{1}{4\pi\varepsilon_0}\int_{\tau'}\frac{\rho_t+\rho_b}{r}d\tau'+\frac{1}{4\pi\varepsilon_0}\int_{\tau'}\frac{\sigma_f+\sigma_b}{r}da' \\ E&=\frac{1}{4\pi\varepsilon_0}\int_{\tau'}\frac{(\rho_f+\rho_b)r_1}{r_2}d\tau'+\frac{1}{4\pi\varepsilon_0}\int_{\tau'}\frac{(\sigma_f+\sigma_b)r_1}{r_2}d\,a' \end{aligned}\right\} \qquad (3)$$

Here; ρ_f free charge density, ρ_b limited charge density, r is the distance between the point where V and E are calculated and the source point where $\rho_f+\rho_b$ the total charge density is formed. r_1 is the unit vector from the source point to the field point and τ' is any volume in which all charges are enclosed.

$$\rho_t = \rho_f + \rho_b = \rho_f - \nabla.P = \frac{\rho_f}{\varepsilon_r} \quad (4)$$

ρ_t is less than ρ_f which is the free charge density, because ρ_b is more deterministic than ρ_f.

At any point in ρ_f homogeneous, isotropic, linear dielectric medium from (4), ρ_b is zero and is zero. Since polarization charges are only on the surface of the dielectric, $\rho_f = 0$ is usually and in this case.

$$\nabla.P = 0$$

$$\int_s D.da = \int_\tau \rho_f .d\tau$$

Since *D,* is the magnitude dependent on *E*; If the equations (3) and (4) are combined, we go one step further for the physical quantity $E = \dfrac{D}{\varepsilon_r \varepsilon_o}$

$$V = \frac{1}{4\pi}\int_{\tau'} \frac{\rho_f}{\varepsilon_r} d\tau' + \frac{1}{4\pi\varepsilon_o}\int_{\tau'} \frac{\sigma_f + \sigma_b}{r} da' \quad (6)$$

The dipole moment per unit volume of the dielectric

$$P = N_p = N\alpha E_{Loc} = N\alpha(E + b\frac{P}{\varepsilon_o})$$

Here N is the number of molecules per unit volume.

$$P = \frac{N\alpha}{1-(N\alpha b/\varepsilon_o)}E$$

$$P = \varepsilon_o \chi_e E$$

Here χ_e is known as the dimensionless-ness constant for the dielectric. b is a constant depending on the dielectric properties [12].

For dielectrics thus the electrical polarization P is directly proportional to the macroscopic electric field intensity *E*, this is also the case within the E_{loc} field.

Gauss's law is related to the flux of the electric field. Where *E* is the electric field and Q_t is the total net charge change surrounded by the surface.

$$\int_s E.da = \int_\tau \nabla.E d\tau = \frac{Q_t}{\varepsilon_o} \quad (8)$$

For dielectrics, Q_t must be enclosed as for free charges.

Q_t here integration is affected by free and enclosed charges both at the surface and in the volume. If this value of Q_t in Gauss's law is eliminated and integrated over the volume,

$$\nabla.E = \frac{\rho_t}{\varepsilon_o} \quad (10)$$

This is true at any point with $\rho_t = \rho_f + \rho_b$. Where ρ_t is the total net charge change. This is the general form of Gauss's law.

When $E = -\nabla V$;

$$\nabla^2 V = -\frac{\rho_t}{\varepsilon_o} \quad (11)$$

It is possible. Equation (11) is the Poisson equation for *V.*

$$\rho_b = -\nabla.P$$

For any dielectric material

$$\nabla.E = \frac{1}{\varepsilon_o}(\rho_f - \nabla.P)$$

$$\nabla.(\varepsilon_o E + P) = \rho_f$$

$$D = \varepsilon_o E + P$$

$$\nabla.D = \rho_f$$

We can write Gauss's law in integral form for *D* as follows.

$$\int_s D.da = \int_\tau \rho_f d\tau$$

From the definition of dielectric displacement,

$$E = \frac{D}{\varepsilon_o} - \frac{P}{\varepsilon_o}$$

In a dielectric, the field density *E*, the sum of these two fields is D/ε_o, due to the free charges,

$$\nabla.(\frac{D}{\varepsilon_o}) = \frac{\rho_t}{\varepsilon_o}$$

and related to limited loads $-P/\varepsilon_o$

$$\nabla.(-\frac{P}{\varepsilon_o}) = \frac{\rho_b}{\varepsilon_o} \tag{12}$$

In this case, we can return to Gauss's law.

$$\int_s E.da = \int_\tau (\rho_f + \rho_b) d\tau \tag{13}$$

Detailed information of the molecule; Since it is related to its shape and charge distribution, this should be taken into account when calculating the average electric field density. But from calculating general terms, we can only care about the shape of the molecule. If the simplest form of the molecule; Considering its round shape, the average area [13].

$$\frac{P}{4\pi\varepsilon_o R^3} = \frac{P}{4\pi\varepsilon_o N R^3} = \frac{P}{3\varepsilon_o N \tau_m} \tag{14}$$

Here *P* is the dipole moment of the molecule, τ_m is its volume (*N* is the number of molecules in the volume) and *R* is the average diameter of the round shaped molecule.

At an advanced stage

$$\tau_m \cong \frac{1}{\mathrm{N}}, E_{loc} \cong E + \frac{P}{3\varepsilon_o}. \tag{15}$$

and we get the best approximations for the local area equation.

Although we consider the round shape of the molecule, we can say $\tau_m \cong \frac{1}{N}$. This means that the entire space is filled with molecules.

4 Electric Field in Dielectric

A dielectric is a type of electrical insulating material that can be polarized by placing it in an electric field. However, unlike the conductor, the electric charge contained in the dielectric does not flow, but shifts only slightly from its equilibrium position, causing dielectric polarization to occur. Due to the dielectric polarity, the positive charge moves towards the negative pole of the electric field while the negative charge moves towards the positive pole of the electric field. This creates an internal electric field within the dielectric which causes the total amount of electric field surrounding the dielectric to decrease. Although the term "insulator" also means low electrical conductivity, however, the term dielectric is often used for insulating materials with a high level of polarization, the magnitude of which is represented by the dielectric constant.

If the field has ρ_f simple geometry, the free charge density an is zero, which is often the case. We always say $\nabla.D = 0$ to find the electrical displacement. The geometric orientation of the field is shown in Figure 2.

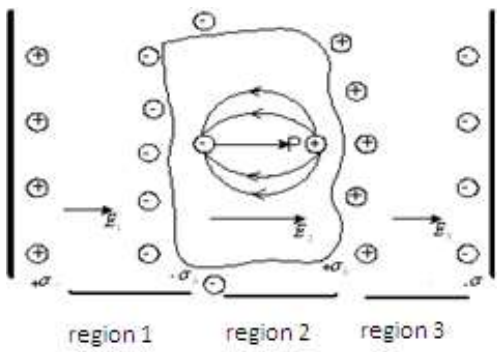

Fig. 2. Representation of the dielectric material placed between the plates with different areas,

$$E_{loc} \cong E + b\frac{P}{3\varepsilon_o} \tag{16}$$

Here b was a constant depending on the properties of the dielectric, and we can say this for a dielectric with a uniform molecule.

In more general terms;

$$P = N_1 P_1 + N_2 P_2 + ...$$

Here, N_1 is the number of molecules of the first type per unit volume. P_1 is the average dipole moment and N_2 is the number of molecules of the second type per unit volume. This theory is not valid for other modifications.

In dielectric material (in region 2),

$$D = \sigma_f\,, \qquad E = \frac{D}{\varepsilon_o} - \frac{P}{\varepsilon_o} = \frac{D}{\varepsilon} = \frac{\sigma_f}{\varepsilon} = \frac{1}{\varepsilon_r} \cdot \frac{\sigma_f}{\varepsilon_o}$$

in 1st and 3rd regions

$$D = \sigma_f\,, \quad E = \frac{\sigma_f}{\varepsilon_o} \ \text{ thus } \ P = p.N$$

where *p* is the electrical dipole moment induced in a single molecule. *P* is polarization, *D* is dielectric displacement *E*, is electric field density, and $\pm\sigma$ is free charges. This is the same inside and outside the dielectric. *D* depends entirely on free charges. *E* decreases inside the dielectric, because $\pm\sigma$ are polarization charges that create a field in the opposite direction.

Potential energy of charge distribution; in the dielectric formation, the integral is given by the form.

$$W = \frac{1}{2}\int_\tau \rho_f \cdot V \cdot d\tau \ , \quad W = \frac{1}{2}\int_\tau (D.E)\, d\tau\,.$$

So the energy density,

$$\frac{dW}{d\tau} = \frac{1}{2}(D.E)$$

5 Forces Affecting Dielectric

In an induced electric field, the dipole is subjected to a torque

$$T = P \times E \tag{17}$$

This torque is related to the area, but the net force is zero. The net force is non-zero. The non-zero net force is valid only in non-homogeneous fields of construction. Thus, one side of the dipole will be subjected to a greater force than the other side. The force per unit volume is written as $(P.\nabla)E$ or,

$$\frac{1}{2}(\varepsilon - \varepsilon_o)\nabla E^2\,.$$

Charged conductors are exposed to electrical forces depending on the nature of another material the dielectric material is in. The force acting on the dielectric in a liquid dielectric will decrease until ε_r. However, this is so provided that the charges and voltage are constant. In this case, the force will increase by ε_r factor.

$$F = (P.\nabla)E\,. \tag{18}$$

This force is the force acting on a single dipole. Like this,

$P = (\varepsilon - \varepsilon_{o)}$ E is written.

In an electrostatic field, $\nabla x E = 0$ will be the resultant force (within homogeneous dielectrics) per unit volume,

$$\frac{1}{2}(\varepsilon - \varepsilon_O)\nabla E^2 = \frac{\varepsilon_r - 1}{\varepsilon_r}\nabla\left(\frac{1}{2}\varepsilon E^2\right) \tag{19}$$

Obviously; the force direction of an increasing amplitude *E* will not be affected by the polarity of the field.

$$\nabla x E = -\frac{\partial B}{\partial t}\,. \tag{20}$$

This equation is one of the four Maxwell's equations. For the linear integral that transforms into a surface integral of $\int_s (\nabla x E).dA = -\frac{d}{dt}\int_s B.da$ Stokes' theorem is used.

Here S is the surface of a boundary closed by the integration path. If this path in space is fixed; we can replace the integration and derivative with the right-hand side of the equation and $\int_s (\nabla x E).dA = -\frac{d}{dt}\int_s B.da$.

We used the partial derivative of B because we need the time rate of change of B at each fixed point. From our equation (20), we know that it is valid on a surface bounded by any boundary $W = -p.E_{loc}$.

Thus, while parallel to E_{loc}, the potential energy is minimum. The heat generation in gaseous and liquid polar dielectrics results from the collision of molecules in the local field. However, it should be noted that the local field can also change due to the changing net dipole moment P with collisions [14].

N being the number of molecules in the unit volume;

$$P = N_p (Coth \frac{PE_{loc}}{kT} - \frac{kT}{PE_{loc}}) \tag{21}$$

This equation is known as the Langeuin equation. In practice, PE_{loc}/kT is more than one small. It becomes $kT \approx 4x10^{-21}$ joules at room temperature, whereas, typical dipole moment is 10^{-30}. Thus, even if the local field is 107 V/m, PE_{loc}/kT is only $2x10^{-3}$.

Thus, we can expand the equation (21) and make it dependent only on u^3. Here $u = PE_{loc}/kT$.

$$P \approx N_p \left[\frac{2+u^2}{2u\left[1+\left(u^2/6\right)\right]} - \frac{1}{u} \right]$$

$$P \approx \left[\frac{1}{2u}\left(2+u^2\right)\left(1-\frac{u^2}{6}\right) - \frac{1}{u} \right]$$

$$P \approx \frac{N_p u}{3} = \frac{N_{p^2}}{3kT} E_{loc} \tag{22}$$

As a practical application of equality; In uni polar dielectrics where the electrical sensitivity is dependent on temperature, Equation (14) and (22) can be combined depending on the polarity.

$$P = N\left(\alpha + \frac{p^2}{3kT}\right)E_{loc}$$

$$E_{loc} = E + \frac{P}{3\varepsilon_o} \quad \text{and} \quad \varepsilon_r = 1 + \chi_e = \frac{\varepsilon}{\varepsilon_o}$$

$$P = \varepsilon_o \chi E$$

$$E_{loc} = \frac{\varepsilon_r + 2}{3} E \tag{23}$$

$$P = \varepsilon_0\left(\varepsilon_r - 1\right)E = N\left(\alpha + \frac{p^2}{3kT}\right)\left(\frac{\varepsilon_r + 2}{3}\right)E \tag{24}$$

$$\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N}{3\varepsilon_o}\left(\alpha + \frac{p^2}{3kT}\right)$$

Multiplying the molecular weight by M and dividing by the bulk density ρ, we obtain a new equation for molecular polarization for these dielectrics.

$$\alpha_m = \frac{M}{\rho}.\frac{\varepsilon_r - 1}{\varepsilon_r + 2} = \frac{N_A}{3\varepsilon_o}\left(\alpha + \frac{p^2}{3kT}\right) \tag{25}$$

This equation is known as the Debye equation. In principle, the Debye equation is used to determine the molecular polarization α and the constant dipole moment P of the molecule. Debye equation; explains the heat production mechanism in swallowed tissues subject to electromagnetic fields [11].

6 Discussion

Marino, Berger, Mitchell, Duhacek, and Becker exposed groups of rats to static electric fields of 0.3 - 19.7 kV/m for 30 days. Vertical (0.6–19.7 kV/m) and horizontal (0.3–9.8 kV/m) exposures had no effect on growth rate and body weight. However, changes in serum protein fractions of rats exposed to vertical fields have been reported [15].

Antipov, Dobrov, Koroleva and Nikitin showed hematological and morphological changes specific to the anxiety stage of the adaptation syndrome caused by static electric field exposure of 50 and 100 kV/m. Exposure also produced reactive and destructive type morphological differences in skeletal muscles and different segments of kinesthetic receptors [16].

Seyhan and Güler reported an increase in the level of thiobarbituric acid reactive substances (TBARS) in plasma, liver, lung and kidney tissues of white guinea pigs exposed to a static electric field of 0.8–1.8 kV/m [17].

7 Conclusions

There is little laboratory study or epidemiological evidence of the link between static fields and health damage. While searching for the link between static fields and cancer, only the magnetic field component is seen as a threat to health. The finite membrane potential of the living cell; Because of its high polarizability, significant forces act on the membrane. In addition, the dielectric responses are nonlinear and affect the cell's metabolic states.

In static fields, the fields have no frequencies and the field value does not change with time. However, if the tissue is mobile in this area, the torque value given by equation (17) will produce the force in equation (18). Since the molecular polarization given in Equation (25) will also change; The static field will act on the tissue due to its dielectric property. In a static area that is thought to be harmless; If the biological tissue is mobile, induction currents are likely to occur in the tissue.

Thanks to our static electric field interaction experiments using rats, the effects of long-term exposure on which biological tissue were investigated. These experiments were carried out within the framework of the theoretical theory given in this article.

Cell and tissue analyzes of the study were performed and interpreted by the relevant scientists. As a result it is aimed to show that the considered static electric field creates induction currents in biological tissues and that harmful effects can also be found.

The engineering significance of the subject is to create accurate cell models. These will be important research topics of the future. As a result, EM exposure conditions should be examined in all areas and national standards should be determined by making necessary corrections accordingly. The continuation of research on this subject is important in terms of scientific and public health.

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