



Review

# Molecular Biological Effects of Weak Low-Frequency Magnetic Fields: Frequency–Amplitude Efficiency Windows and Possible Mechanisms

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**Abstract:** This review covers the phenomenon of resonance-like responses of biological systems to low-frequency magnetic fields (LFMF). The historical development of this branch of magnetobiology, including the most notable biophysical models that explain the resonance-like responses of biological systems to LFMF with a specific frequency and amplitude, is given. Two groups can be distinguished among these models: one considers ion-cofactors of proteins as the primary targets for the LFMF influence, and the other regards the magnetic moments of particles in biomolecules. Attention is paid to the dependence of resonance-like LFMF effects on the cell type. A radical-pair mechanism of the magnetic field's influence on biochemical processes is described with the example of cryptochrome. Conditions for this mechanism's applicability to explain the biological effects of LFMF are given. A model of the influence of LFMF on radical pairs in biochemical oscillators, which can explain the frequency–amplitude efficiency windows of LFMF, is proposed.

**Keywords:** low-frequency magnetic fields; ion parametric resonance; calcium; radical pairs; cryptochrome; mitochondria; biochemical oscillations



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## 1. Introduction

Magnetic fields are constantly present in the environment. The natural geomagnetic field and its fluctuations accompanied the evolution of life on Earth. The current strength of the geomagnetic field varies from the equator to the poles from approximately 25 to 65  $\mu\text{T}$ , and its direction varies in space in a rather complex way. The alternating constituent of natural magnetic fields is represented by low-frequency fluctuations, mainly due to regular and irregular processes in the Earth's magnetosphere–ionosphere current system. The range of these magnetic fluctuations rarely exceeds hundreds of nT, and most natural variable magnetic fields are recorded in the range of up to 10 Hz [1]. Anthropogenic magnetic fields are superposed on the natural magnetic background due to the development of technology over the past century. These fields vary significantly in their characteristics [2]. The overall intensity of anthropogenic magnetic fields is steadily increasing year by year. In this regard, it is essential to understand the influence of the magnetic environment on organisms.

Weak (conditionally not higher than 100  $\mu\text{T}$ ) low-frequency magnetic fields (LFMF) are of great interest among the fluctuating magnetic fields. Their energy does not exceed the thermal noise, i.e., LFMF cannot directly affect an elementary act of chemical reactions of kT order [3]. At the same time, the biological effects of weak LFMF are often described in the literature [4]. Moreover, these effects can manifest themselves at specific values of the frequency and amplitude of the LFMF and be absent at other frequencies and amplitudes of the same order [5,6]. The researchers working in this field apply their efforts to clarify the mechanisms responsible for such biological responses. Over the last few decades, several hypotheses have been proposed in this regard. However, there is no definitive understanding of the formation of a specific biological response to LFMF.

# Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields

**Martino Gandolfo, S.M. Michaelson, A.  
Rindi**



## **Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields:**

*Biologic and Clinical Effects of Low-frequency Magnetic and Electric Fields* J. G. Llauro, Anthony Sances, J. H. Battocletti, 1974      *Index of Publications on Biological Effects of Electromagnetic Radiation (0-100 GHz)* James B. Kinn, Elliot Postow, 1981      **EPA-600/9**, 1981-03      Handbook of Biological Effects of Electromagnetic Fields, Third Edition - 2 Volume Set Charles Polk, Elliot Postow, 1995-12-21

The first edition of this book has been recognized as the standard reference on biological effects of electric and magnetic fields from DC to microwaves. But much has changed in this science since the book's original publication in 1986. With contributions from eighteen leading researchers, this latest edition includes authoritative discussions of many new developments and will quickly become the new must-have resource handbook. Dielectric properties of biological tissue are thoroughly examined, followed by chapters on physical mechanisms and biological effects of static and extremely low frequency magnetic fields. New chapters on topics that were treated very briefly in the first edition now receive extensive treatment. These topics include electric and magnetic fields for bone and soft tissue repair, electroporation, and epidemiology of ELF health effects. The chapter on computer methods for predicting field intensity has been substantially revised to describe new numerical techniques developed within the last few years and includes calculations of power absorbed in the human head from cellular telephones. The chapter discussing experimental results on RF interaction with living matter now contains information on effects of very high power, very short duration pulses. A new appendix on safety standards is based on the latest publications of governmental as well as quasi-governmental organizations such as the U.S. Council on Radiation Protection in the United States, Europe, and Australia. With all its revisions, this updated version of the CRC Handbook of Biological Effects of Electromagnetic Fields provides the most comprehensive overview available of this rapidly changing science.

*Biological Effects and Dosimetry of Nonionizing Radiation* Martino Gandolfo, 2013-11-11

During the last 35 years, there has been considerable development and increase in the number of devices that emit nonionizing radiant energies. These energies, such as radiofrequency including microwaves, are used in all sectors of our society for military, industrial, telecommunications, medical, and consumer applications. This increase in sources of nonionizing radiant energies has resulted in growing interest on the part of government regulatory agencies, industrial and military physicians, research workers, clinicians, and environmentalists. Although there is information on biologic effects and potential hazards to man from exposure to microwave radiofrequency energies, considerable confusion and misinformation has permeated not only the public press but also some scientific and technical publications. Because of the complexity of the interactions of nonionizing radiation in biological systems, an interdisciplinary approach is necessary to assess and elucidate the problems that evolve as this field advances and as the use of these energies expands. It is important to maintain a proper perspective and assess realistically the biomedical effects of these radiant energies so that the worker or general public will not be unduly exposed nor will research development and beneficial utilization of these energies be hampered or restricted by an

undue concern for effects which may be nonexistent or minimal in comparison to other environmental hazards

**Electrical and Biological Effects of Transmission Lines**, 1982      **Biological effects of power frequency electric and magnetic fields**, 1989      *Biological Effects and Dosimetry of Static and ELF Electromagnetic Fields* Martino Gandolfo, S.M. Michaelson, A. Rindi, 2013-03-09 The editors are pleased to present these Proceedings of the V Course of the International School of Radiation Damage and Protection of the Ettore Majorana Centre held in Erice Italy in November 1983. The lectures and discussions among leading scientists in various disciplines of physics engineering biophysics cellular biology physiology and medicine from 11 countries are included in this compilation. In this volume we have attempted to explore all aspects of the interaction of static and Extremely Low Frequency ELF 0-300 Hz electric and magnetic fields with biological tissue systems and whole organisms we considered dosimetry and what is known or presumed concerning basic interactions responses from the cellular and molecular level to the whole organism. Discussions of medical applications as well as epidemiologic investigations related to high voltage transmission were held with critiques of methodologies used and recommendations for future approaches. Consideration was also given to the necessity and principles of setting protection standards for man and the environment. We believe this is the first attempt to put all this information together into one volume to provide perspective for understanding the influence of static and ELF electric and magnetic fields on biological systems. We hope our attempts were successful. Martino Gandolfo Sol M Michaelson Alessandro Rindi

**ACKNOWLEDGEMENTS** This is the Fifth Course of the International School of Radiation Damage and Protection of the Ettore Majorana Centre for Scientific Culture directed by Professor A. Zichichi      *Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports* United States. Naval Medical Research and Development Command. Electromagnetic Radiation Project Office, 1975      Seafarer ELF Communications System Draft Environmental Impact Statement for Site Selection and Test Operations: Appendix E: Biological and ecological information United States. Naval Electronic Systems Command, 1977      **Role of the BPA in the Pacific Northwest Power Supply System**, 1981      The Role of the Bonneville Power Administration in the Pacific Northwest Power Supply System Including Its Participation in the Hydro-thermal Program United States. Bonneville Power Administration, 1977      Biological Effects of Electromagnetic Waves Curtis C. Johnson, Morris L. Shore, 1977      Man and His Planet, an Unauthorized History James E. Strickling, Jr. James E. Strickling, 2008-10 Strickling examines both views of the creation controversy by employing each side's supporting arguments to refute its own conclusions. He sheds new light on a number of ancient texts      **Seafarer ELF Communications Systems**, 1977      *Emerging Electromagnetic Medicine* Mary E. O'Connor, Richard H.C. Bentall, John C. Monahan, 2012-12-06 *Emerging Electromagnetic Medicine* presents the latest research findings in the field of electromagnetic radiation. The book discusses the research of current active researchers in terms of synthesizing and sharing their ideas on the use of electromagnetic fields in diagnostic and therapeutic medicine now and in the future including the

benefits and risks involved The book consists of three parts prefaced by a brief historic perspective Section I describes the theoretical concerns and actual mechanisms involved Section II covers current preclinical studies performed in vivo and in vitro concerning the biological action of the electromagnetic radiation and Section III reports on actual clinical applications of electromagnetic therapy and also the current machinery used to do so      **Biological Effects of Extremely Low Frequency Electromagnetic Fields** Richard D. Phillips,1979      Human Health and the Environment Second Task Force for Research Planning in Environmental Health Science (U.S.),1977      Human Health and the Environment--some Research Needs United States. Task Force for Research Planning in Environmental Health Science,1977      *The Physical Basis of Electromagnetic Interactions with Biological Systems* Leonard S. Taylor, Augustine Y. Cheung,1978

## Whispering the Secrets of Language: An Psychological Quest through **Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields**

In a digitally-driven earth where screens reign supreme and quick connection drowns out the subtleties of language, the profound strategies and emotional nuances hidden within phrases frequently get unheard. However, situated within the pages of **Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields** a charming fictional value pulsing with natural thoughts, lies an exceptional quest waiting to be undertaken. Written by a skilled wordsmith, this charming opus encourages readers on an introspective trip, gently unraveling the veiled truths and profound impact resonating within ab muscles cloth of each word. Within the emotional depths of this poignant evaluation, we will embark upon a genuine exploration of the book is core themes, dissect its captivating publishing model, and succumb to the strong resonance it evokes deep within the recesses of readers hearts.

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### **Table of Contents Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields**

1. Understanding the eBook Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - The Rise of Digital Reading Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Advantages of eBooks Over Traditional Books
2. Identifying Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - User-Friendly Interface
4. Exploring eBook Recommendations from Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields

- Personalized Recommendations
- Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields User Reviews and Ratings
- Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields and Bestseller Lists
- 5. Accessing Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields Free and Paid eBooks
  - Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields Public Domain eBooks
  - Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields eBook Subscription Services
  - Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields Budget-Friendly Options
- 6. Navigating Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields eBook Formats
  - ePub, PDF, MOBI, and More
  - Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields Compatibility with Devices
  - Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields Enhanced eBook Features
- 7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Highlighting and Note-Taking Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Interactive Elements Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
- 8. Staying Engaged with Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
- 9. Balancing eBooks and Physical Books Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
- 10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
- 11. Cultivating a Reading Routine Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Setting Reading Goals Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Carving Out Dedicated Reading Time

12. Sourcing Reliable Information of Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Fact-Checking eBook Content of Biologic And Clinical Effects Of Low Frequency Magnetic And Electric Fields
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning
  - Utilizing eBooks for Skill Development
  - Exploring Educational eBooks
14. Embracing eBook Trends
  - Integration of Multimedia Elements
  - Interactive and Gamified eBooks

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