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# THE EFFECTS OF ELECTROMAGNETIC FIELDS ON THE NERVOUS SYSTEM

by

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A dissertation submitted in partial fulfillment

of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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Approved by Arthur W. Guy
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We have carefully read the dissertation entitled The Effects of Electromagnetic Fields on the Nervous System submitted by Chung-Kwang Chou in partial fulfillment of the requirements of the degree of Doctor of Philosophy and recommend its acceptance. In support of this recommendation we present the following joint statement of evaluation to be filed with the dissertation.

This dissertation deals with a very difficult and controversial subject concerning the interactions of electromagnetic (EM) fields with the central and peripheral nervous system. It provides a very interesting and complete historical background on the subject and points out some of the problems and weaknesses of past and current work reported in the literature which in part is responsible for the present confusion in international safety standards relating to nonionizing radiation. The dissertation reflects the candidate's firm grasp of the fundamentals and the techniques of the two major but considerably different areas of science: neurophysiology and EM fields. The candidate has applied the most quantitative aspects of each of these areas to focus his attention on this difficult interdisciplinary problem. He outlines the methods of quantitative measurements of the fields both outside and inside of biological subjects exposed to EM radiation and describes in complete and lucid detail his original work on developing new techniques for exposing biological preparations both in vitro and in vivo. These new techniques allowed the candidate to carry out original work that significantly advances the knowledge of the quantitative relationship between nonionizing radiation dosage, temperature and electrophysiological characteristics of peripheral nerve, superior cervical ganglion, and nerve muscle preparations exposed to EM fields. He has shown that with proper temperature and dosimetry control the acute exposure of isolated nerve preparations to high power electromagnetic energy does not produce effects that cannot be produced by a simple application of heat. This is contrary to what many other researchers have shown in the past with similar preparations under less controlled exposure conditions.

One of the most important elements in the dissertation, and a major contribution to understanding of the interaction of EM fields and the mammalian auditory system is the work elucidating the microwave hearing pheonomenon which has defied explanation since World War II. In fact, only in the last year has any significant progress been made concerning an explanation of the phenomena and a good portion of that progress is the original work of the candidate reported by the dissertation. The candidate's experiments to determine thresholds of the effect as a function of background noise and his very remarkable first recordings of the cochlear

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microphonics associated with the phenomenon is very significant in advancing the knowledge on this subject. The candidate's exceptional ability both within engineering and neurophysiology allowed him to develop the equipment and make the recordings of these important physiological signals that other researchers have sought without success. In summary, we feel that the candidate has written an outstanding dissertation in reporting his new and very exciting research findings.

DISSERTATION READING COMMITTEE: Arthur W. Guy

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Otto D. Wiener

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I am greatly indebted to my advisor, Professor Arthur W. Guy, for his stimulating thought,guidance, encouragement and patience throughout the course of this study.

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# I. Introduction

## 1.1 Historical background

Long before electromagnetic (EM) waves were discovered and described by Heinrich Hertz in 1888, Luigi Galvani in 1791 observed the contraction of a frog nerve-muscle preparation stimulated by a remote spark from an electrostatic machine [1]. Much later, Tesla in 1891 observed the biological effect of high frequency EM radiation on an entire organism. In the same year, D'Arsonval placed his object inside a solenoid that had a high frequency current flowing in its windings, and he observed vasodilitation and hypotension in his subjects [2]. In 1895, Danilewsky observed the effects of high frequency EM fields on a neuro-muscular preparation [3]. During the first 30 years of the twentieth century most of the work being done was connected mainly with diathermy and physiological reactions to the heating effect of EM radiation [4]. After that, the first peak of interest in this problem occurred during the decade from 1930 to 1940 when technological advances made possible the generation of powerful EM fields. During this period, much valuable work was done, mainly on the physical and chemical properties of matter and certain simple biological systems, with very little attention to hazard problems [3]. Research in this area diminished in the early 1940's when World War II started, and was greatly over-dominated by the research on ionizing radiation due to the development of nuclear weapons and of other, peaceful uses of nuclear energy after the war [5].

In 1956, when there was a growing concern over the possible hazards associated with the operation and use of radar and other radio frequency electronic equipment, the United States started a "Tri-Service Program" (Army, Navy, Air Force) to coordinate this EM radiation research. This Tri-Service research program addressed itself essentially only to the

problem of thermal hazard, without any effort on the low level radiation effects. At the end of the Tri-Service program in 1960, United States research in this area decreased to a very low level and remained there until the late 1960's.

The most recent boost of research activity in the United States stems from a combination of several factors. The increasing use and output level of EM emitting equipment as well as the low level radiation effects reported from Russia and East European countries have re-raised concern over the biological effects and potential hazards of EM radiation. Another problem causing concern, described in detail by Don Justesen [6], was a political event which occurred in the Soviet Union. In the early 1960's, U.S. security experts discovered that the Soviets were directing beams of microwave energy at the U.S. Embassy. The major impetus was provided by the activities of the Office of Telecommunications Policy, within the Executive Office of the President, which established the Electromagnetic Radiation Management Advisory Council (ERMAC) to review, advise and make recommendations on potential problems associated with the use of the EM spectrum. After a comprehensive review and analysis of this problem, the ERMAC report called for an increased effort in this area [5]. At present, there are 13 federal agencies supporting this research in the United States, which reflects the high interest and vigorous research activity in this area.

In contrast to the sporadic efforts in the United States, the Soviets have maintained a steady research activity over the past 20 years. Along with the Soviet Union and the United States, Poland, Czechoslovakia, and recently Britain, Germany, and France have also been working on the same problem. A considerable amount of work on low level effects is

reported in Russian and East European literature. Presman [1] and Gordon [7] of the Soviet Union and Marha [3] of Czechoslovakia have well summarized their past research results in their books.

Because of the unresolved differences in reported biological effects and in the exposure and safety standards derived from them, recent international symposiums and conferences (such as the 1973 Warsaw meeting [8], the 1974 New York Academy of Sciences meeting [9], and the 1975 International Microwave Power Symposium [10]) have brought together scientists from different nations. The objectives of these meetings were: to exchange current information about the EM radiation effects, to recommend and stimulate further research needs and approaches, to encourage international cooperation in relevant research, and to consider ways of achieving an international dosimetric standardization and safety standard [8].

Since people became interested in the effects of EM fields, the effects on the nervous system have been a most interesting problem to the investigators not only because this system is very sensitive in reaction to environmental changes, but also because of its tremendous electrical activities. The past interests are reflected in numerous publications on this subject and in the special sessions in the Warsaw and New York meetings.

1.2 Significance of the EM radiation research

A considerable interest has been raised around the world in studying the effects of EM waves on human health. The frequency range receiving the most attention in terms of biological interaction is in the microwave spectrum 300 to 10,000 MHz. This is due to the widespread use of high power equipment in highly populated areas and to the better energy absorption characteristics of tissues in this frequency range [11].

The effects being sought, of microwaves on the biological system, are opposites: 1) medically beneficial effects and 2) harmful effects.

At the present time little is known about either. This is illustrated by the fact that at present the maximum recommended safe power density for long term human exposure varies from 10 $mW/cm^2$ in the United States, to as low as 10 $\mu W/cm^2$ in the Soviet Union and Eastern European countries. The former standard was formulated primarily from research results on tissue heating considerations, while the latter was based on research relating to the central nervous system and behavior effects.

Research results conclusively show that for frequencies between 1200 MHz and 24,500 MHz, exposure to power density of 100 $mW/cm^2$ for one hour or more could have definite thermal effects. At power densities below 10 $mW/cm^2$, evidence of pathological change is equivocal. Although some Soviet investigators describe the thermal nature of microwaves, the majority stress non-thermal or specific meicrowave effects at molecular and cellular levels, in contrast to studies performed in the United States that generally reflect the physiological response of the organism to the thermal burden imposed by nicrowaves. A considerable body of literature has grown in the Soviet Union on transient functional changes following low dose, less than 10 $mW/cm^2$, nicrowave irradiation studied by conditional response experimentation. The Soviets have strongly and repeatedly stressed that the central nervous system must be considered as being moderately or highly sensitive to radiation injuries. The work in this area has been criticized because of limited statistical analysis of data, inadequate controls, and lack of quantification of results [12].

Although there are several thousand papers in the literature pertaining to the subject, a considerable amount of the reported data is so qualitative in nature that more questions have been raised than answered. Quantitative research is urgently needed from a joint physical and biological science approach to clarify the conflicting research data and resulting conclusions which now exist [13] [14].