Chapter 4
Bioelectromagnetism

Andrew W. Wood
Swinburne University of Technology, Australia

ABSTRACT

Bioelectromagnetism covers a number of sub-disciplines, but is firstly concerned with the ability of living systems to generate electrical currents and magnetic fields. Secondly, it covers the susceptibility of tissue to be stimulated by these currents or fields, and the ability of some organisms to sense low level fields. Thirdly, it also covers the possible health implications of exposure to low level environmental fields, including those associated with the transmission and distribution of electric power and of telecommunication systems. Fourthly, it presents the various therapeutic uses of these fields. Some of the effects are well-established, whereas others remain controversial. This chapter discusses the nature of this uncertainty.

4.1. CHAPTER OBJECTIVES

This chapter will survey the emerging discipline of Bioelectromagnetism, which can be sub-divided into three overlapping but somewhat distinct areas: Bioelectricity; Biomagnetism and Bioelectromagnetics. The first two are strongly allied with diagnostic techniques in clinical medicine, but the third has extremely important implications in sociology and public policy. These aspects will be explored, along with the basic engineering principles underlying the biological effects.

4.2. INTRODUCTION

Bioelectromagnetism covers a number of sub-disciplines, but is concerned with the ability of living systems to generate electrical currents and magnetic fields. It also covers the susceptibility of tissue to be stimulated by these currents or fields and the ability of some organisms to sense low level fields. It also covers the possible health implications of exposure to low level environmental fields, including those associated with the transmission and distribution of electric power and of

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telecommunication systems. On the other hand, there are therapeutic uses of these fields. Some of the effects are well-established, whereas others remain controversial. This chapter will discuss the nature of this uncertainty.

4.2.1. The Phenomenon of Electrical Events Generated by Biological Tissue

A number of medical diagnostic techniques are based on measuring electrical activity of regions of the body. Examples which immediately spring to mind are the Electrocardiogram (ECG) and Electroencephalogram (EEG) which measure electrical activity associated with the heart and brain respectively. These phenomena in turn relate to the electrical activity of single cells, each possessing a standing potential of around 0.05 V across the membrane which forms the cell margin. This potential is subject to random fluctuations due to thermal agitation and discrete diffusion events. The origin of this potential will be discussed in section 4.5 and the magnitude of these fluctuations are obviously important when considering the effects of external electric and magnetic fields (EMFs). The property of cell membrane potential is shared by both animal and plant cells as well as bacteria (Novo, Perlmutter, Hunt, & Shapiro, 1999). On the other hand, it is uncertain whether viruses, which sometimes have envelopes that may derive from their hosts, produce electrical activity. Some animal cells (such as nerve and muscle cells) possess the property of excitability, that is, an ability to rapidly respond to stimuli by depolarisation (that is, reduction in membrane potential) or potential reversal (that is, the outside of the cell becomes negative rather than positive). Such excitability represents the basis of nervous impulses and muscle contraction, as we will see in later sections. Non-excitable cells (such as skin cells or plant cells) still show some interesting electrical phenomena, such as rectification and conductivity modulation, which are linked to their function. Cells also contain internal membranes associated both with the cell nucleus and with the cavernous network of internal spaces known as the Endoplasmic Reticulum (ER). The nuclear membrane is, in fact, a double membrane which interconnects with the ER. It does not entirely enclose the nucleus – there are nuclear '*pores*' allowing a limited exchange of small molecules between nuclear and cytoplasmic spaces. The mitochondria (the '*powerhouses of the cell*') within the cytoplasm also possess double membranes. However, it is the electrical and diffusive properties of the cell, or plasma, membrane, which forms the outer boundary membrane of the cell, which is the focus of attention in Bioelectromagnetism.

As mentioned, the cell membrane is obviously crucial to the detection of small external electrical signals apparently buried in thermal noise. Whilst acting as a bag to contain the cell's contents, the membrane also possesses unique properties of selectivity and fluidity, controlling the rate of transfer of metabolites into and out of the cell (Guyton & Hall, 2006). The cell surface is able to recognize other cells of a similar type, adhering to them to form cell layers. Some cells such as white blood cells (leukocytes) are able, via the membrane, to engulf, digest or deactivate bacteria or viruses as part of the '*immune response*'. The cell membrane is in fact a mere 8 - 10 nm in thickness, which when combined with a trans-membrane potential difference (PD) of up to 100 mV implies an internal electric field of 10 MV/m, close to dielectric breakdown of the membrane material (mainly phospholipid). The passage of many ions, such as Na^+ K^+ and Ca^{++} is controlled via gated channels through the membrane, the gate (and hence conductance) being under the control of the trans-membrane PD (and also other factors, such as temperature). Cell signalling between nerves and muscles is via rapid reversal of this potential, a regenerative process ensuring non-dispersive and non-attenuating propagation of regions of this potential reversal along the length of *the* nerve or muscle fibres. These po-

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