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CHAPTER II.5.10 BIOELECTRODES

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INTRODUCTION

Bioelectrodes are sensors used to transmit information into or out of the body. This chapter: (1) introduces the reader to the basic reactions that occur at an electrode–electrolyte interface; (2) explains how these processes define the type of electrode; (3) explores some simple equivalent circuit models for the electrode–electrolyte interface; (4) reviews the factors influencing material selection for electrodes; and finally (5) looks at some applications of such electrodes. Although the fundamentals discussed apply to both recording and stimulating electrodes, this chapter focuses on stimulating electrodes in the material selection and application sections, because of their recent emergence as effective treatment options (see pacemakers and defibrillators in Chapter II.5.3.C.) Also, see Chapter II.5.12 that addresses this subject from a somewhat different perspective.

Surface or transcutaneous electrodes used to monitor or measure electrical events that occur in the body are considered as monitoring or recording electrodes. Typical applications for recording electrodes include electrocardiography, electroencephalography, and electromyography. Electrodes used to transmit information into the body influence specific processes that occur in the body, and are considered as stimulator electrodes. In all of these applications the electrodes are used to transmit voltage or current waveforms to specific target areas in the body for either direct control of a bioelectric event or for indirect influence on the target area through a stimulated chemical change. Such stimulator electrodes are used in cardiac pacemakers and defibrillators to maintain or restore sinus rhythm, in transcutaneous electronic nerve stimulators for pain suppression, in neural stimulation systems for applications ranging from epilepsy control to auditory augmentation, in polarizing devices for intranscutaneous drug delivery, and in stimulators for tissue healing/regeneration.

ELECTRODE–ELECTROLYTE INTERFACE

In 1800 Volta demonstrated that the electrode–electrolyte interface was the source of electrical potential, and initiated his research on direct current electricity. The nonlinearity of this interface with current led Georg Ohm (1826) to use a thermopile as a source of electrical potential, and resulted in the law that bears his name. However, the origin of the term "electrode" is attributed to one of the most prolific researchers in electrochemistry, Faraday (1834). In 1879 Helmholtz established the first model for the electrode–electrolyte interface (Helmholtz, 1879). Several more complex models of this interface were proposed by Gouy (1910) and Stern (1924). This section will explain the basic reactions at the electrode–electrolyte interface, how they define a specific electrode type, and finally the make-up of this interface.

Faradaic and Nonfaradaic (Capacitive) Processes

Bioelectrodes can interact with the body fluids (electrolytes) in two primary ways – faradaic and nonfaradaic (summarized in Figure II.5.10.1). An electrode may establish ohmic contact with the surrounding environment, thereby transferring electrons across the electrode–electrolyte interface via oxidation and/or reduction reactions. All such charge-transfer processes are governed by Faraday's law (i.e., the amount of chemical