6. Bioelectrets: Electrets in Biomaterials and Biopolymers

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With 14 Figures

Charge and polarization storage via the electret state has now been found in many biomaterials. The importance of the electret effect in these materials has to do with biomedical applications as well as with its possible role in more fundamental biophysical phenomena. As biomaterials, electrets have found interesting applications as antithrombogenic surfaces. Other uses have been mentioned in the literature, such as the stimulation of tissue growth in bone and special artificial membranes. The electret effect has also been found in most biopolymers of importance such as proteins, polysaccharides, and some polynucleotides. Fundamental macromolecules of biology, such as collagen, hemoglobin, DNA, and chitin, not only exhibit the effect, but may have various sources, or, to use a more biological term, “compartments”, for polarization and charge storage: dipoles and ions bound to the molecules.

One of the most important aspects of electret research in biophysics is that water bound to biopolymers in the so-called structured form (also called bound water, or biowater) may also be induced into the electret state. Electret investigation techniques were used to study this most important form of water in conjunction with the biopolymer.

The electret state has been considered in various biophysical models as a basis for the understanding of membranes, neural signals, biological memory in regeneration, electrical mediation in tissue growth, and other phenomena. One of the most interesting models claimed to depend on an induced ferroelectric metastable state similar to the electret is Fröhlich's model for coherent longitudinal polarization waves in biological systems. Fröhlich waves have been invoked to explain enzyme action, and recently the electret effect was found in various important enzymes in the solid state such as trypsin, urease, and others. For biomedical applications and in molecular biophysics, the electret concept begins to open new avenues for research, which seem to justify the usage of the term bioelectrets.

6.1 Introductory Remarks

It is interesting to observe that the first electret was made with a material of biological origin: carnauba wax, from the carnauba palm tree of Brazil. This was the material originally used by Eguchi [6.1] to verify experimentally the
theoretical proposal of Heaviside [6.2], who coined the name electret. In fact, carnauba wax proved to be, for many years, the main material for electret investigations. The samples prepared by Eguchi in 1922 are still electrized and subject to monitoring measurements in the laboratory of Eiichi Fukada in Japan. The other pioneer of electret investigations, Gross, also investigated carnauba wax electrets in many of his fundamental papers (listed in [6.3a, b]). Electret research gradually moved to simpler materials like ionic and organic crystals and polymers where fundamental solid-state properties could be correlated with the electret behavior [6.4–8]. More recently, however, the electret effect was studied in materials of biological origin like proteins, and now the picture emerges that the electret effect may in fact be a universal property of biopolymers in general such as polypeptides, polynucleotides, and polysaccharides [6.9a] (see also [6.9b], which may be the first paper on TSD from a protein–hemoglobin).

For biomedical applications, polymers with good biological compatibility (such as teflon) are also considered as biomaterials, and though, strictly, they are not biopolymers, they will be treated as biomaterials in this chapter. In this way we are led to consider the electret properties of artificial polymers such as teflon and polysulfonate films which are of importance for biological or medical applications.

The techniques used to study the electret effect in biomaterials (and biopolymers) are essentially the same as for general electret research [e.g., thermally stimulated depolarization current (TSDC)], and we shall not discuss them in detail here since they are covered in other chapters of the present volume or in the literature [6.7]. Specific changes in these techniques and important details required for electret investigation in biomaterials will be explicitly discussed, however.

Some general observations are nevertheless required in relation to experimental techniques in the special case of biomaterials.

a) Materials of biological origin in general cannot easily be put in single-crystal form. For most biopolymers, for instance, fibers or powder samples are used. Sometimes (as in the case of DNA and cellulose), a film may be obtained. In this case, the orientation of the macromolecule in relation to the film may be investigated by X-rays or optical techniques, and may be important for the interpretation of the effects observed. A typical case is the natural electret effect in keratin found in highly oriented samples of biological origin [6.10], which will be discussed in detail in another section.

b) The purity and origin of samples of a biological nature become a very important parameters electret investigations, and, in general, great attention has to be given to the preparation of samples, preferably with the assistance of biochemists and biologists. Here electret investigations really need to be interdisciplinary.

c) Many biopolymers change their properties by denaturation, hydration (or dehydration), oxidation, and even as a result of exposure to light. Careful attention should be given to all these factors during electret investigations, and