LETTER TO THE EDITOR

Error Introduced in the Dielectric Constant Measurement by Electrode Polarization

Dear Sir:

In a paper published in your journal under the title "Piezoelectric and related properties of hydrated collagen" by E. Fukada et al. (1), we understand that the values recorded as ϵ', the real component of the complex dielectric constant, reflect the electrode polarization behavior at low frequencies.

To clarify this point, we quote from Schwan (2): "The sum of the electrode-electrolyte interface polarization and biological impedances may be erroneously identified with the latter in the absence of any knowledge about electrode polarization.... The total impedance thus observed [sample and electrode-electrolyte interface] is usually measured as an equivalent parallel RC combination ... for most practical purposes of interest:

$$R = R_s + R_p + (R\omega C)^2 \cdot R_s," \tag{1}$$

where R_s and C_s are sample resistance and capacitance; R_p and C_p are polarization resistance and capacitance; and ω is angular frequency. And

$$"C = C_s + 1/\omega^2 R^2 C_p." \tag{2}$$

Also the electrode polarization capacitance is best characterized by a power function of the frequency

$$C_p \sim f^{-m}, \tag{3}$$

where f is the frequency and m slowly varies with the frequency. Typically for metal electrodes, m varies from 0.2-0.3 at low frequencies to 0.5 at high frequencies, near 10 kHz. If the sample conductivity is high, i.e. R_s is small and hence R is small, the second term in Eq. 2 becomes large and the electrode polarization capacitance is recorded in addition to the sample capacitance. The frequency dependence of ϵ' formulated as $f^{-3/2}$ in the text (and shown as $f^{-1.8}$ in Fig. 9) may be obtained by direct substitution of the above values in Eq. 2. Techniques to correct for electrode polarization have also been discussed in many articles by the same author (3).

As to the inverse proportionality of ϵ'' with respect to frequency, it is indicative of low frequency conductivity.

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REFERENCES

1. FUKADA, E., H. UEDA, and R. RINALDI. 1976. Piezoelectric and related properties of hydrated collagen. *Biophys. J.* **16**:911.
2. SCHWAN, H. P. 1963. Determination of biological impedances. *Phys. Tech. Biol. Res.* Vol. 6, Electrophysiological Methods. **1**:323.
3. SCHWAN, H. P. 1966. Alternating current electrode polarization. *Biophysik.* **3**:181.

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