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Conductivity and Photoconductivity in Egg White

Abstract. *Activation energies of 1.47 to 2.94 electron volts were obtained in egg white. These values are too large to be consistent wtih the large observed currents if one uses a semiconductor model and indicate that the standard semiconductor model is inappropriate for this biological material.*

The values of electrical resistivity and activation energy of liquid and crystalline albumin found by different investigators (*1, 2*) vary considerably. Although it is not pure albumin, egg white upon being dried becomes a hard, clear, amber-colored solid that can be handled easily. Conductivity studies on it encounter neither the barrier problems associated with powders nor the electrode problems associated with solutions, and, except for being heated and dried, the natural substance is not treated in any way. We therefore investigated some of the electrical properties of the material in the belief that they might prove a useful adjunct to the findings for albumin, by serving as a bridge to values for a biological material in the natural state.

Samples were prepared from chunks of egg white that had been boiled in water for 15 minutes and dried in air for several days. The hard, translucent solid of less than half its original volume was painted on two sides with silver epoxy, to which leads were attached. A guard ring encircling the remaining sides prevented surface currents from being recorded. A Chromel-constantan thermocouple was cemented to the guard ring with insulating epoxy.

For potentials under 1.5 volts a battery and potentiometer were used; for potentials between 1.5 and 100 volts a high-voltage supply was used. Currents were measured with a picoammeter. Temperature was varied with a thermoelectric heater-cooler attached to two copper rods that held the sample on the sides with electrodes, the latter being electrically insulated from the rods. The sample was contained in a light-tight box and could be illuminated through an optical shutter by a 100-watt mercury lamp, Corning glass filters isolating different regions of the spectrum.

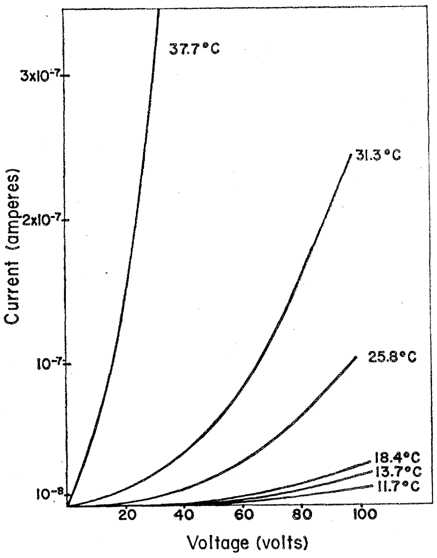

Fig. 1. Current as a function of voltage at different temperatures for a sample 0.8 by 0.8 by 0.5 cm thick.

The absorption spectrum, measured with a Cary-14 spectrophotometer, was essentially flat over the visible and near-ultraviolet range. For a sample thickness of several millimeters, radiation from the untraviolet to 5500 Å is absorbed totally. From 5500 Å to longer wavelengths 1 or 2 percent is transmitted, accounting for the sample's translucency and yellow color.

Curves of dark current as a function of voltage, at different temperatures, for a sample 0.8 by 0.8 by 0.5 cm thick, are shown on a linear scale in Fig. 1. The current is not ohmic; it depends roughly on the square of the voltage. Figure 2 shows the current as a function of the reciprocal temperature on a semilogarithmic scale. There seem to be several slopes, the steepest at higher temperatures, yielding an activation energy ΔE equal to 2.94 ev in the expression

$$i = i_0\, e^{-\Delta E/KT}$$

where i is the current density, i_0 is a constant, K is Boltzmann's constant, e is the exponential, and T is the absolute temperature. The middle range yields a slope corresponding to ΔE of 1.47 ev. Although at lower temperatures the slope seems to flatten and then become steeper, a single slope has been drawn. The behavior in this last range is shown more clearly in Fig. 3, where the logarithm of the current, at 1 volt, is plotted against the reciprocal temperature.

When the current is proportional, not to the voltage, but to some higher power of the voltage, an activation energy may still be relevant when the same activation energy is applicable to all voltages. It is possible, in that case, that the origin of the voltage dependence is not related to the source of current but is an independent phenomenon.

What emerges from these measurements are, first, large activation en-

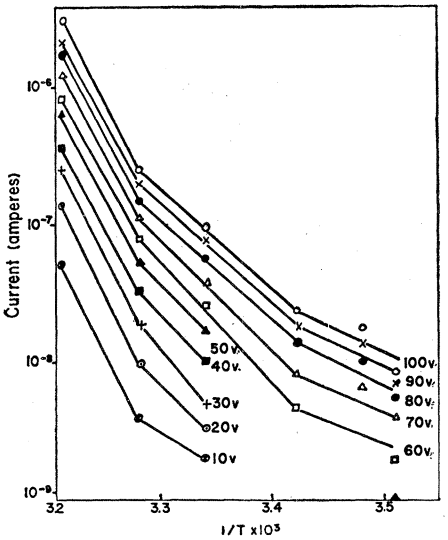

Fig. 2. Current as a function of reciprocal temperature for different voltages.

ergies, which preclude their representing different energy levels. Second, the observed activation energies are independent of voltage despite the current's rough dependence upon the square of the voltage; the curves for different voltages (Fig. 2) have the same shape. (There is evidence that moisture plays some role. When the sample was tested after an interval of some weeks, its dark current had decreased by about an order of magnitude, presumably because of further drying.)

Figure 3 shows the photocurrent, which is indistinguishable from the dark current except at lower temperatures. At 7°C, the current is doubled by 5 mw of light from 4200 to 5000 Å falling on the sample (between the electrodes). The increase could be produced by ultraviolet, blue, and green light. However, red light of the same intensity as that of each of the other wavelength regions failed to produce an increase over the dark current, indicating that the observed increase is indeed a photocurrent, and not the effect of heating (*3*). Lowering the temperature further did not result in a further increase in photocurrent. Instead, the current leveled off, and declined at temperatures below 4°C. (Some light could reach the electrodes, which might lead to possible artifacts due to light sensitivity of the silver. However, our discussion pertains to the dark current rather than the photocurrent.)

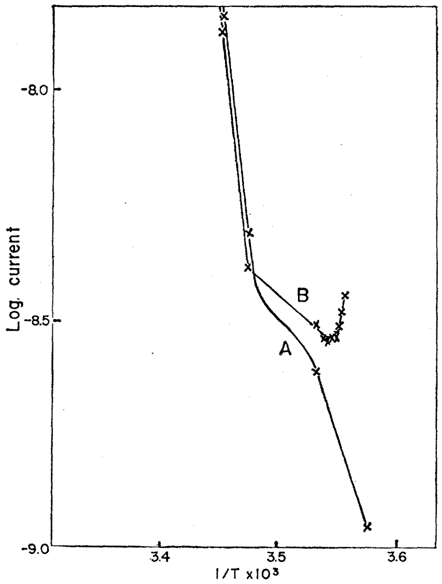

Fig. 3. Log current as a function of reciprocal temperature at 1 volt in the dark (curve A) and under illumination by 5 mw of light from 4200 to 5000 Å (curve B).

It is difficult to reconcile activation energies of 1.47 to 2.94 ev with currents of 10^{-8} to 10^{-6} amp/cm^2 with a semiconductor model. This is a difficulty that applies to many studies of biological materials. For ΔE equal to 1.47 ev the exponential factor equals 10^{-26}. From the expression commonly employed for i_0

$$i_0 = 2n_0 e\mu\epsilon$$

where n_0 is the carrier density, e is the electronic charge, μ is the mobility, and ϵ is the field strength, and substituting the largest feasible values for n_0 and μ, 10^{22}/cm^3 and 1 cm^2/volt sec (although mobilities of 1000 have been postulated for tunneling or similar processes) (*1*), we find that the magnitude of i_0 is 10^5, yielding a current of 10^{-21} amp/cm^2. Kallmann and Pope (*4*) have argued that the above expression applies only when charges originate at the surface, and that the appropriate expression for the maximum current density thermally produced in the bulk material is

$$i = n_0 e\delta d e^{-2\Delta E/KT}$$

where ΔE is the measured quantity and equals half the energy gap, d is the sample thickness, and δ is the collision factor. If δ equals 10^{12} sec^{-1}, the pre-exponential factor is 10^{15}, and the exponential factor 10^{-52}, yielding a current of 10^{-37} amp/cm^2, a strong indication, since the measured currents are much greater, that we are dealing with surface effects.

One alternative to using standard semiconductor theory would be to conclude that the measured activation energy is not that required to deliver charges, but relates, perhaps, to the resistance of the sample. One might envisage charge production at the electrode-sample interface with low activation energy (*4*), combined with transport through the bulk with high activation energy (*5*) (precluding transport through a conduction band). The sample might be "porous," with the "pores" or channels more conductive than the material and becoming increasingly conductive with temperature. The activation energy is then a measure of the effectiveness of the channels in transporting charges from the surface. Like normal semiconductor electron and hole conduction, protonic conduction is ruled out because the measured currents are too high.

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Histone Synthesis in vitro by Cytoplasmic Microsomes from HeLa Cells

Abstract. *HeLa cell microsomes incorporate labeled amino acids in vitro into acid-soluble proteins which have the same electrophoretic mobility as histones isolated from the purified HeLa cell nuclei. The capacity to synthesize histones in vitro is dependent on deoxyribonucleic acid synthesis in the cells from which the microsomal fraction is prepared.*

The accumulative synthesis of histones in mammalian cells is temporally coupled to the synthesis of DNA during chromosome replication (*1–3*). This relationship, as well as the close physical combination of histones with the DNA, suggests that specific DNA-histone as-