

THE THICKNESS OF THE WALL OF THE RED BLOOD CORPUSCLE

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(Accepted for publication, February 9, 1935)

Measurements of the impedance of erythrocyte suspensions made by Fricke (1) and McClendon (2) have been interpreted as possibly leading to the conclusion that the impedance is due to a thin layer of non-conducting material of molecular dimensions surrounding the erythrocytes. Assuming a dielectric constant of 3, Fricke's calculations give a thickness of 33 Å, which led him to suggest that the non-conducting layer was unimolecular. The low conductivity would point to a layer of lipid molecules, for it is difficult to see how hydrated protein molecules could form a layer of such low conductivity.

Since any calculation of thickness from impedance measurements depends on assumptions as to dielectric constant, a discussion of the probable value of this constant for thin films becomes important. If the lipid layer is solid, 3 is a probable value, being the average value for organic substances in the solid state. If the lipid layer is liquid, as is probably the case in the erythrocyte, more factors have to be taken into consideration, for organic liquids generally have considerably larger dielectric constants.

The main contribution to the dielectric constant of naturally occurring lipoids comes from the polar groups (carboxyl, amino, *etc.*) of the molecules. The contribution of the hydrocarbon part of the molecules is minute. When an electric field is applied to a lipid in the solid state the electrical dipoles of the polar groups are unable to rotate the molecules as much as if the substance were liquid, and consequently lipoids have much lower dielectric constants in the solid than in the liquid state. It follows from this, however, that if the molecules in a liquid could be prevented from rotating the substance would have the same dielectric constant both in the liquid and in the

solid state. Such a condition is found in the case of a unimolecular liquid film, formed at either an oil-water or an air-water interface, for, though the film is liquid, the polar groups are fixed in the interface and the molecules are not free to rotate. Consequently such very thin lipid layers, as *e.g.* that of the erythrocyte, which consist of little more than two oriented unimolecular films, should also have low values for their dielectric constants. This argument, however, is not entirely satisfactory as it stands, since there will be a considerable proportion of water molecules in the interfacial films. The argument would be satisfactory if it were possible to show that the mixture of water molecules and polar groups which composes the interfacial films also has a dielectric constant of approximately 3. Fortunately an experimental proof of this can be derived from studies of unimolecular films at air-water interfaces; films at air-water and lipid-water interfaces are so closely similar that a direct comparison is quite justifiable so far as the polar groups are concerned.

Consider any unimolecular film. The dipole moment of each molecule in the film is μ . On the average the dipoles will be oriented at an angle α to the plane of the film; the vertical component of each dipole will therefore be $\mu \sin \alpha$. This oriented array of dipoles will produce a potential ΔV perpendicular to the plane of the film, such that

$$\Delta V = \frac{4 \pi n \mu \sin \alpha}{D}$$

or

$$\mu \sin \alpha = \frac{\Delta V \cdot D}{4 \pi n} \quad (1)$$

where n is the number of molecules per sq. cm., and D is the dielectric constant of the phase containing the polar groups.

In this equation α , and D are unknown in the first instance, and ΔV and n can be measured from the film. μ can readily be determined by measurements made on the film substance when in solution in some inert solvent. Since there are two unknowns present the value of D cannot be obtained from this equation as it stands.

We can, however, obtain a maximum value for D . The maximum value of $\sin \alpha$ is 1, and is obtained when the dipoles are oriented perpen-

dicular to the plane of the film. Thus if a value for D is calculated on the assumption that the dipoles are vertical (*i.e.* $\sin \alpha = 1$), whereas actually they are at an angle to the vertical (*i.e.* $\sin \alpha < 1$), the calculated value of D will be too great. The calculated value cannot possibly be less than the true value. Consequently, if in equation (1) we write $\sin \alpha = 1$ and calculate the values of D corresponding to various values of n and ΔV , the minimum value of D obtained by this calculation will be either equal to or greater than the true value of D for the film concerned. The following table contains a series of values for D obtained with films of various substances, the data for the calculation of which have been taken from the published and unpublished work of N. K. Adam and his collaborators, J. B. Harding and J. F. Danielli. In one case, that of the nitriles, the value of D has already been published.

Compound-forming film	D
Aliphatic ester.....	4.2
“ acid.....	5.4
“ alcohol.....	6.5
“ ketone.....	6.4
“ nitrile.....	6.7
“ dibasic ester.....	3.0
Sterol alcohol.....	4.1
“ ketone.....	2.5

As these values are to be regarded as maximum values only, it appears improbable from this table that the value of the dielectric constant of such systems of polar groups can be much greater than 3. It would therefore appear that Fricke's assumption is justified even in the case of a liquid layer, provided the film is not more than two molecules thick. If the layer is more than two molecules thick there will be little to prevent free rotation of the molecules of the liquid layers between the two interfacial films, and the dielectric constant would be correspondingly greater than 3.

In the previous discussion the case of a continuous layer only has been considered. Similar considerations will also apply to a mosaic membrane (3), since the same factors are involved, and also to any emulsion of oil in water in which the surface area is large compared

with the volume of the oil droplets. In fact phenomena of the type discussed here must be taken into consideration in all cases in which the ratio of surface to volume is not insignificant.

SUMMARY

Fricke's assumption, that the dielectric constant of the erythrocyte wall is 3, is discussed. The assumption is approximately correct in the case of a solid layer of any thickness, and in the case of a liquid layer of not more than bimolecular thickness. For liquid layers of greater thickness the dielectric constant may be several times greater than 3. Calculated values based on experimental determinations are given of the dielectric constants of the polar groups of unimolecular films.

My thanks are due to Professor E. N. Harvey and Dr. W. Wilbrandt.

REFERENCES

1. Fricke, H., *Phys. Rev.*, 1925, **26**, 682.
2. McClendon, J. F., *J. Biol. Chem.*, 1926, **69**, 733.
3. Danielli, J. F., *J. Cell. and Comp. Physiol.*, in press.