arrangement recommend it for use in place of the reflection galvanometer, not only for null indications but also in many cases of current and voltage measurement. Sensitivities of a like order with the more modest wall-type instruments are readily attained.

The very highest sensitivities are to be obtained of course with reflection galvanometers, and here too the microscope may be employed to extend the range of the instrument to much smaller currents and voltages than those ordinarily observed. Light from a vertical lamp filament, passing through a convergent lens, falls upon the galvanometer mirror and comes to focus before the objective of a horizontal comparator microscope instead of upon the customary scale. The observer uses the comparator in the usual way, setting the cross-hair or index upon the edge of the filament image and taking readings at the micrometer head.

On an ordinary scale one would perhaps be able to detect an image shift of one fifth of a millimeter. With a comparator suitably arranged a displacement one one hundredth as large is definitely observable. In a recent test a filament of a 40 watt tungsten lamp was used as source, while a lens of 60 cm focal length produced the image. The mirror was of good quality, plane and circular, and had a diameter of 1.1 cm. At a distance of 200 cm from the mirror a comparator with a magnification of thirty diameters was located. The definition of the image was greatly improved by the insertion of a green Wallace filter at the comparator objective. With the mirror in a fixed position the comparator index was set upon the edge of the image ten times and the micrometer head readings recorded. The average deviation of these readings from their mean was .0001 cm, which shows that any rotation of the mirror, so long as the image remained within the range of the comparator, could by a single setting be measured with a probable error of 1/20 second of arc.

With the galvanometer before me at present—a style to be found in most university physical laboratories and one without claims to high sensitivity—these figures suggest the possibility of measuring currents of the order of 10^{-11} amperes. Unfortunately, however, the perturbations to which these types are subject prevent making full use of this unusual magnification.

The angular sensitivity described is due in part to the use of the comparator screw, by which the observer is relieved of the task of estimating the precise position of the image with respect to a series of scale rulings. It is well not to forget that this objectionable operation, which limits the accuracy of scale measurements of all kinds, may generally be avoided, if the ends justify the effort, through mechanical devices such as we have considered here. The ordinary vernier supplies the simplest and best illustration.

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SPECIAL ARTICLES

AN HYPOTHESIS ON CELL STRUCTURE AND CELL MOVEMENTS BASED ON THERMODYNAMICAL CONSIDERATIONS[1]

ALL living matter is principally built up of aqueous solutions of substances which have the property of lowering substantially the surface tension of water. It is known that these substances will tend to reach an equilibrium by accumulating at interfaces. This is just a consequence of the application of a well-known thermodynamical law: a system always tends towards a state of equilibrium where the free energy will be the minimum compatible with its total energy. If a droplet of such a solution is abandoned in a small hollow in a rock, or sprayed into the air, under any circumstances where it will be momentarily separated from the bulk, its constituents in solution will concentrate in the surfaces, the solubility of some of them, in case of a complex solution, will be affected by the presence of salts and of CO_2, coagulation will follow, and it will be surrounded by a membrane. On the other hand, since the works of Gibbs and Boltzmann, we know that the state of equilibrium predicted by thermodynamics for any material system is always "the most probable state compatible with its total energy, potential and kinetic." Hence, we may say that "the most probable equilibrium configuration of such a system is the cell form," which is equivalent to saying that the state of thermodynamic equilibrium of a system composed of proteins[2] in solution with salts, under the conditions stated above, is the cell form. However, the size of the original droplet is not indifferent, and the foregoing observations, based on experimental evidence[3] and theoretical considerations, are only likely to be applicable in the case of droplets small enough to coat themselves with an adsorbed layer of protein of sufficient thickness in a very short time. The smaller the droplet, the more rapidly its surface layer will be saturated with protein.

[1] From the Laboratories of The Rockefeller Institute for Medical Research.

[2] Or any other organic substance of high molecular complexity endowed with the same properties with regard to surface tension. The term "protein" is used throughout this paper for the sake of brevity, but the experimental facts and the hypothesis may apply as well to other compounds found in the cells and in the plasma, for instance, or to a combination of them.

[3] du Noüy, P. L., *J. Exp. Med.*, 1922, xxxv, 575, 707; SCIENCE, 1924, lix, 580.

It has been shown that the static value of surface tension in pure serum, for instance, is reached in about twenty minutes in watch-glasses, where the depth of the liquid is about 3 mm, and consequently the longest vertical path traveled by molecules is 1.5 mm. In the case of a spherical droplet of the same diameter (3 mm), it would require about the same time to reach the equilibrium, that is to say, to coat it with a layer of concentrated protein. But the same phenomenon would require only about 1 second if the droplet had a diameter a thousand times less, namely 3μ. In a finely atomized spray of, say, a 6 per cent. solution of proteins, a large number of droplets would consequently, under certain circumstances (ultra-violet rays, CO_2 atmosphere, HCl gas, etc.), be readily transformed into a cell with a membrane three hundred to four hundred times more viscous[4] than the inside liquid, and partially insoluble in water. According to the time that elapses between the spraying and the moment the droplet strikes water again, cells of different sizes may be formed. Thus, the initial order of magnitude of these cells is determined somewhat by the concentration of the solution and the time defined above.

Furthermore, it has been shown that protein solutions, under certain conditions of concentration, volume and surface, could organize monomolecular layers, or monolayers, at the interfaces. This was first proven experimentally in 1924.[5] The curves expressing the static values of surface tension of such solutions, drawn in function of the concentration, showed marked minima at certain critical concentrations. These minima, being due to a static arrangement of oriented, fixed molecules, can not be accounted for on a thermodynamical basis. The Gibbs formula may enable us to calculate the static value of an egg albumin solution at a concentration of 1/138,000 and at a concentration of 1/142,000, but these points are on a smooth curve, and if, as happens, a minimum occurs between these two points, due to organization of molecules, no thermodynamic formula as yet can foresee this fact, which depends on the size and shape of the individual molecule. Thus, one may expect a sudden change in the surface tension at the interface between air and solution, or between two solutions, not necessarily as a consequence of a chemical reaction, as has always been assumed so far, but also as a consequence of a very slight change in the concentration of either the outside or the inside liquid, according to whether one considers the inside adsorbed layer or the outside adsorbed layer. A relative change in the concentration of the order of 2/100 (from 1/138,000 to 1/140,000, for instance) may bring forth a decrease of surface tension of a few dynes (three to eight in the case of egg albumin—air interface), on a limited area of the cell, if this change in concentration only affects part of the surrounding liquid. This area will, of course, immediately bulge out under the influence of the internal pressure. Changes in concentration of such order of magnitude should be expected to go on almost constantly, as a consequence of the fluctuations of density, under the influence of the slightest cause: foreign bodies adsorbing protein molecules, particles going into solution, etc.). Therefore, the changes in surface tension may be considered as occurring constantly. The time required to organize such a layer over a limited area of a cell must be very small, if the concentration of the solution inside the cell is such as to make the formation of a monolayer possible. Indeed, the aforesaid hypothesis requires one condition, namely, that the concentration and the size of the cell be related in a certain way. In our experiments (watch-glasses), monolayers were produced at dilutions around 1/140,000 and 1/190,000 for egg albumin and around 1/10,500 for serum. In these experiments, the ratio $\frac{\text{surface}}{\text{volume}}$ which evidently determines for every concentration the possibility of forming the monolayer, was equal to 13.2 approximately.[6] It is clear that in order to obtain a monolayer formation with pure serum, for instance, it would be necessary to use a much smaller vessel, so that the ratio $\frac{\text{surface}}{\text{volume}}$ would be increased 10,500 times, namely, up to 137,000. Such an enormous ratio can exist only in a very small vessel, or a vessel whose shape is that of a flat disk. A simple calculation shows that it should have such inside dimensions as, for instance, 5μ in diameter and 0.2μ in thickness, in which case the ratio $\frac{S}{V}=150{,}000$. Under such conditions, the formation of a monolayer is possible from the inside, with a concentration of proteins corresponding to that of pure serum. This calculation assumes, of course, that this cell contains no nucleus or bodies capable of adsorbing the protein (mitochondria). In the latter case, the size of the cell could be larger without a concurrent decrease in the ratio. Should this ratio

[4] du Noüy, P. L., SCIENCE, 1925, lxi, 117.

[5] du Noüy, P. L., *J. Exp. Med.*, 1924, xxxix, 37; xl, 133.

[6] It has been shown experimentally (footnote 3, and Third Colloid Symposium Monograph, 1925) that the concentrations at which the monolayers were observed, in the case of protein solutions, depended on the ratio $\frac{S}{V}$ of the container, and were proportional to the value of this ratio. This fact was recently confirmed in the case of sodium oleate (unpublished experiments).

decrease, then a more dilute solution would be required to build up the monolayer; should it increase by flattening of the cell or change in its shape, or should adsorbing bodies be formed inside the cell, a more concentrated solution would be necessary to build it. And reciprocally, if it be assumed that the size of the cell is determined somewhat by the possibility of forming, under certain conditions, oriented monolayers of proteins, the slightest change in the concentration, as might be brought about by changes in the pH which affect the solubility of these substances, will determine a change in the ratio $\frac{S}{V}$, and the cell will grow or diminish in size, or alter its shape. Consequently, the normal concentration of biological fluids might be one of the factors determining the size of the living cells. Should our hypothesis be true, they could not exist outside of a certain range of dimensions, and their activity would depend, among other factors, on how near the critical concentration they may be with respect to their ratio $\frac{S}{V}$; indeed, if these three quantities happen to be balanced in such a way as to make the building of monolayers possible, they will be in a constant state of activity, as anything affecting the concentration will change the surface tension, while in turn any phenomenon affecting the surface tension on one point will determine a variation in the ratio $\frac{S}{V}$, which will result in a fluctuation in density in some other part of the cell, with a corresponding change in surface tension.[7] In certain cases, where the externally adsorbed layer seems to be of constant thickness (red cells), the solid oriented layer of adsorbed serum proteins gives a certain rigidity to the cell. This adsorbed layer, the order of magnitude of which is about 40 Ångstroms (40×10^{-8} cm), is probably fixed on an inside layer, the thickness of which can not be computed. Thus the ratio $\frac{S}{V}$ of the inside of the cell may be larger than the outside ratio and correspond to a higher concentration of proteins, not to mention the possibility of inside adsorbing elements.

It is needless to say that the preceding hypothesis is given only tentatively and that the writer does not wish to lay any emphasis on it. However, considering the somewhat striking coincidence of the figures, and the interesting departure from thermodynamic equilibria realized by the formation of oriented layers, it is possible to conceive that phenomena of a similar nature play a part in the still mysterious behavior of cells. It throws no light, however, on the inside structural elements of the cell, and the nucleus, for example, remains unexplained.

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[7] It is usually admitted that the cell content is rather a concentrated solution of proteins. If this is true it becomes necessary to suppose that there is a considerable surface of adsorption inside the cell, in addition to those which can be seen under the microscope.

A NEW AREA OF CARBONIFEROUS ROCKS IN MEXICO

THE locality which furnished the material for this notice was discovered by Mr. Parker A. Robertson, a geologist of the Mexican Gulf Oil Company. He made a small collection at the original locality and later, with Mr. J. M. Muir, a geologist of "La Corona" Compania Mexicana, he made a larger one at a nearby point. The material thus obtained was sent to Dr. L. W. Stephenson, and he, recognizing that the fauna was Carboniferous in age and consequently of less interest to himself than to me, obligingly placed it in my hands for examination. This note is published by the kind permission of the authorities of the Mexican Gulf Oil Company.

The fossil locality is in Peregrina Canyon, eleven kilometers west twenty-two degrees north of Victoria in eastern Mexico, and is remote by at least five hundred miles from any authentic area where Paleozoic rocks have as yet been reported. A possible exception is an unconfirmed occurrence of undivided Carboniferous rocks in the San Carlos Mountains about seventy miles northeast of Peregrina Canyon.[1] This discovery of Mr. Robertson's is of considerable interest, on this score alone, but in addition the fauna is of an age and facies quite unexpected. Had it proved to be Permian or Pennsylvanian, the discovery would have been interesting but not surprising, but the fauna proves to be early Mississippian and of a type less comparable to the contemporaneous faunas of our border states such as the Lake Valley limestone or the Escabrosa limestone, than to faunas of Missouri or of Ohio.

The most characteristic features of the fauna from Peregrina Canyon may be set down here, although a more searching description will be given in another place. The most abundant fossils, probably, belong in the genus *Syringothyris,* and represent three types more or less closely related to species in the lower Mississippian of Iowa and Missouri. A large *Reticularia* scarcely distinguishable from *R. pseudolineata* is also abundant, and *Athyris lamellosa,* though more rare, is highly distinctive. *Spiriferina, Delthyris* and *Chonetes* are present as well, but *Productus* appears to be rare. It is, however, represented by a large species of the semireticulate type, closely resembling a common member of the Waverly fauna of Sciotoville, Ohio. Altogether, the faunal aspect is clearly early Mississippian and probably equivalent in time value to the Burlington and Keokuk of our Mississippian section.

[1] See geologic map of North America, 1911.