here just as well, since there is a far-reaching parallelism between the rules of antagonism for the isolated fish and the egg. Thus Loeb and Wasteneys have shown that the fish *Fundulus* dies more slowly in a pure $m/100$ or $m/50$ KCl solution than when 10 molecules of NaCl are added to 1 molecule of KCl; while the toxic action of KCl is prevented when 17 or more molecules of NaCl are added to 1 molecule of KCl.[3] The writer has recently found that the same fact is true for the eggs of *Fundulus,* with this difference only, that much higher concentrations of KCl are required to demonstrate the phenomenon in the egg than in the fish; and that a much wider range of antagonistic salts can be used in the case of the egg than in that of the fish. This difference, however, can easily be accounted for by the difference between the membrane of the egg and the skin of the fish.

The fact that the stimulating action of salts upon nerve and muscle is inhibited by Ca may also be due to the prevention of the diffusion of the stimulating salts into the nerve or muscle by the Ca.[4]

The writer is in no position to state whether or not Osterhout's[5] interesting observations on the electric conductivity of *Laminaria* may be interpreted as diffusion phenomena, since it is not possible in that object to separate the direct action of the salts on the membrane from that upon the protoplasm. The death of a cell under the influence of a salt must be ascribed to an action of the salt upon the protoplasm, but this action can only take place after the salt has been able to diffuse through the membrane.

The diffusion of certain electrolytes through a membrane seems to depend in addition to the osmotic pressure of the salt in solution upon a second effect which the writer has called the general salt effect.[6] This effect he attributes to a combination of the salt with certain constituents of the membrane, presumably proteins.

3. There are certain kinds of antagonism which seem peculiar to phenomena of irritability and which can not be found in phenomena of diffusion. Thus the larvæ of the barnacle are unable to swim when put into a mixture of $NaCl + KCl + CaCl_2$ until some $MgCl_2$ is added; they are also unable to swim in a mixture of $NaCl + KCl + MgCl_2$ without $CaCl_2$.[7] It is not strictly correct to call this a case of antagonism between Ca and Mg, since in mixtures of $CaCl_2$ and $MgCl_2$ (without $NaCl +$ KCl) the animals are no more able to swim than in a mixture of NaCl and KCl alone or of $NaCl + KCl + MgCl_2$. Either Ca or Mg suffices to counteract the diffusion of $NaCl +$ KCl through the membrane of *Fundulus,* and it is not necessary to add both. The writer had first observed this type of antagonism in the rhythmical contractions of the jellyfish *Polyorchis*[8] and it was afterwards observed by Meltzer and Auer in mammals.[9] It may be peculiar to special sense organs or other animal structures since the writer was not able to observe it in *Euglena.*

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THE ELECTRICAL CONDUCTIVITY OF SOLUTIONS AT DIFFERENT FREQUENCIES

V.[1] ON THE MEASUREMENT OF THE TRUE AND APPARENT ELECTRICAL CONDUCTIVITIES AND THE INDUCTANCE, CAPACITY, FREQUENCY AND RESISTANCE RELATIONS

For the past two years the authors have been engaged in a detailed study of the passage of alternating currents at different frequencies through solutions of electrolytes. For a source of current we have used several generators but especially the Type *B* Vreeland

[1] Summary of a paper given at the Urbana meeting of the American Chemical Society, April 18, 1916.

oscillator sold by the Western Electric Company, as it gives a pure sine wave form and the frequency of the current can be varied at will over a range of 160 to 4,200 cycles. We have also arranged with Vreeland for Leeds and Northrup to sell a smaller instrument giving 500, 750, 1,000 and 1,500 cycles per second.

Curtis coils were used in our bridge, as by this means we could practically eliminate inductance and capacity effects which are a source of error when inductive resistances are used. Tuned telephones sold by the Western Electric Company were used so that the minimum could be detected as accurately as possible.

Several different bridge arrangements have been used for measuring the capacities, inductances and resistances. In order to measure a "cell constant" it is necessary to determine both the resistance and the capacity given by the standard solution of ($N/10$, $N/50$, $N/1,000$) potassium chloride at different frequencies. A substitution method suggested by Curtis for measuring resistances was used, as it prevents errors due to any changes in the resistances of the bridge coils, or of the inductance, caused by variations in temperature, and allows the experimenter to read the resistances directly instead of having to make involved calculations.

Resistance measurements made on a given solution in a given cell by using (1) an inductance in series with the cell and (2) a condenser in parallel with the resistance arm checked to within 0.001 per cent. when all necessary corrections are made.

We have used a new type of cell in which each electrode is supported in four places, so that it can not move and thus change the cell constant. We have also made all joints to come below the surface of the water so that there can be no error from evaporation of the solvent. One criterion of good cells is that *whatever the solutions used the ratios of the resistance of any solution in two such cells, or of two solutions in any cell, must be constant to within 0.01 per cent. at infinite frequency.*

It was found that resistance readings on a given cell with a given solution can be repeated easily with an average deviation within ± 0.001 per cent.

Even in the old type cells, and when no special precautions were taken in transferring the solutions, resistance measurements on different parts of the same solution in the same cell checked to within 0.01 per cent.

When solutions of electrolytes were allowed to stand in cells for 24 hours, the resistance of the solution in the cells with platinized electrodes did not change, while in those with bright electrodes the resistance increased at the rate of about 0.003 ohm per hour.

There is no measurable change in the resistance of a solution, or the capacity of the cell, with change in voltage from 0.25 to 8 volts, provided the cells, solutions and containers are kept scrupulously clean, and the polarization voltage is kept below 1.23 volts. Dr. G. H. Gray is studying this problem by the use of the oscillograph.

The capacities in cells with bright electrodes vary from 10 to 1,000 microfarads, while in cells with platinized electrodes they range from 500 to 5,000 microfarads.

There is no measurable change in the resistance of a solution with change in frequency from 600 to 2,000 in our cells with *platinized electrodes* 1 inch in diameter, and such cells therefore give approximately the true electrical resistance of solutions at any such frequency. The ratios of the resistances of $N/5$, $N/10$ and $N/20$ NaCl measured in two different cells with platinized electrodes show a deviation of not over 0.01 per cent. at these frequencies, which is hardly more than the experimental error.

In cells with *bright platinum electrodes* there is a change in resistance with change in frequency from 250 to 3,000 cycles and higher, and this change depends upon several factors: (1) As the concentration of any given solution is decreased, and therefore the resistance increased, the change in resistance with change in frequency is decreased; (2) as the area of the electrode surface is increased the change in resistance with change in frequency is decreased; (3) as the area of the electrode surface is increased the inductance necessary to obtain a balance is decreased, and hence the apparent "capacity" of the cell is increased; (4) the higher the apparent "capacity" of the cell, the smaller the change of resistance with change in frequency; (5) solutions of different salts having about the same resistance in the same cell give approximately the same change in resistance with change in frequency from 600 to 1,000 cycles.

By comparing the resistances of $N/10$ and $N/20$ NaCl in two cells, one of which had bright and the other platinized electrodes 1 inch in diameter, it was seen that the ratio for the cell with bright electrodes was much lower than that for the cell with platinized electrodes, but as the frequency was increased the ratio for the cell with bright electrodes approaches that for the cell with platinized electrodes. Extrapolating the resistance for the cell with bright electrodes to infinite frequency, the ratio was found to differ by only 0.01 per cent. from that given by the platinized electrodes. It is thus shown that the true electrical resistance of solutions can be measured or calculated in cells with bright platinum electrodes only at infinite frequency.

Saturation of bright and platinized electrodes with hydrogen produces no appreciable change in the "capacity" of the cell at 60 cycles. This and much other evidence seems to show that the "capacity" does not arise from a neutral gas layer deposited on the electrodes and acting as an air condenser. It is probably due to a "double layer" of the electrolyte and the "contact potential" arising from changes of concentration resulting from electrolysis and to the reverse electromotive force coming from the deposition of ions on the electrodes.

The inductance necessary to balance the "capacity" of the cell is nearly but not quite inversely proportional to the square of the frequency. As this relation holds true for a "leaky" condenser the cell seems to act as a simple condenser with a "leak."

As the frequency of the alternating current is increased the change in resistance of a given solution in a given cell, and also the inductance necessary to balance the capacity of the cell, are decreased, and both approach zero at infinite frequency. The ratio of the difference in the inductance in millihenries to the difference in the resistance in ohms between 600 and 1,000 cycles has a constant value of about 2.00.

Mr. Henry P. Hastings is continuing the work by making measurements of resistance, capacity and inductance at much wider range of frequency, namely, 60, 250, 500, 750, 1,000, 1,500, 2,000 and 3,000 cycles. He has confirmed the fact that a change in frequency produces a change in inductance necessary to balance the cell capacity which corresponds fairly closely to the equation $KL = 1/Cw^2$. At lower frequencies he observes easily a third harmonic produced by the cell. Mr. Hastings has also confirmed our work by extrapolating the resistances of solutions in cells with bright electrodes to infinite frequency and showing that they approach the values given by the same solutions in cells with platinized electrodes.

He has also found that the ratio of the *change of resistance* which is sometimes 5 per cent. of the resistance, to the *change of inductance* produced when the frequency is changed is approximately constant.

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ON THE REGULARITY OF BLOOMING IN THE COTTON PLANT

In 1915 the writer carried on some experiments on the water requirement of cotton, in connection with which the blooming records of a number of plants were kept. In looking over these records, there appears to be a sort of regularity in which the blooms opened and two of these records which showed the greater regularity are herein given.

To those unacquainted with the habit of growth of the cotton plant it will be well to first call attention to the different kinds of branches as shown on the accompanying diagrams. On the one of plant No. XIV., those branches numbered one and two are known as vegetative branches; these occur on all plants of this species so spaced as to have freedom in