THE RESISTANCE OF THE HUMAN BODY TO DIRECT AND ALTERNATING CURRENTS.

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THE object of the experiments described below was to obtain the resistance of the living human body to relatively large currents of electricity, both alternating and direct, and to determine whether this resistance is constant with currents of varying intensity.

For the first part of the work a Duncan dynamometer was used, which was provided with special fixed coils having a great number of turns, making it sufficiently sensitive to measure the currents used. The calibration of the instruments showed that the deflections were practically proportional to the square of the current strength, and that its constant was .00084 amperes.

The method employed was to take a reading with a dynamometer in series with a non-inductive resistance of 1550 ohms, and then throw the instrument in series with the resistance to be measured and take a second reading. The results given below were from hand to hand. Connection was made to the circuit through a couple jars of sal-ammoniac solution. The four fingers of each hand were thrust down into a jar of the solution so that they were just covered by the liquid. The hand above the surface was kept dry. The connection between line and solution was made by means of large battery carbons. Measurements taken with both carbons in one jar showed that the resistance of the carbons and liquid could be neglected. It was also found that, with the currents used, the polarization at the carbons was inappreciable.

The table below gives results with sal-ammoniac of density 1.035 and also with a concentrated solution. These were taken with direct currents and with alternating currents of 62 periods per second.

The first column gives the reading through the resistance of 1550 ohms and the dynamometer, whose resistance is 856 ohms. The second is the reading through the body from hand to hand. The third gives the square root of the ratio of the first to the second. The figures of the fourth column were obtained by multiplying the corresponding numbers of the third by 2406 and subtracting 856 from the product. The fifth column gives the amperes through the body, and the sixth, the potential difference of the terminals in the carbon plates.

	I.	II.	III.	IV.			
	Reading through 1550 ohms.	Reading through body.	$\sqrt{\frac{I}{II}}$	Resis- tance.	Cur- rent.	E.M.F.	
Alternating current.	10.0	10.0	1.00	1550	.0026	4.0	Fingers in NH ₄ Cl 1.035.
	15.2	15.0	1.01	1574	.0032	5.0	
	19.0	20.0	.98	1502	.0039	5.8	
	17.0	16.0	1.03	1622	.0034	5.5	
	27.0	27.0	1.00	1550	.0044	6.8	
	27.0	27.0	1.00	1550	.0044	6.8	
			Mean.	1558			
Direct current.	12.0	8.0	1.22	2079	.0024	5.1	
	21.0	16.0	1.14	1887	.0033	6.2	
	30.0	29.0	1.02	1598	.0045	7.2	
	41.0	38.0	1.04	1646	.0052	8.6	
	12.0	10.5	1.07	1718	.0027	4.6	
			Mean.	1786			
Alternating current.	3.2	3.3	.98	1502	.0015	2.2	
	5.5	5.8	.97	1478	.0020	2.9	
	8.8	9.1	.98	1503	.0025	3.7	
	14.5	15.0	.98	1502	.0032	4.8	
			Mean.	1497			
Direct current.	9.9	8.2	1.09	1766	.0024	4.2	Concen- trated NH ₄ Cl.
	17.0	14.5	1.08	1742	.0032	4.6	
	24.0	21.5	1.06	1644	.0039	6.4	
	19.1	17.2	1.05	1670	.0035	5.8	
	14.3	13.0	1.05	1670	.0030	5.0	
			Mean.	1698			

The dynamometer has considerable self-induction, so that the current lags when it is used in series with the non-inductive resistance. On the other hand, if there be any electrolytic action in the body it acts as a capacity introducing a lead. If θ be the angle of lag when the non-induction resistance is used, and φ , the angle of lead or lag with the body in the circuit, while R is the resistance of the body and ρ the ratio of column III, we have

$$R + 856 = 2406 \rho \frac{\cos \varphi}{\cos \theta}.$$

The calculations of the table were made on the assumption that $\frac{\cos \varphi}{\cos \theta}$ is equal to unity. To see if this assumption is warranted, we measured the self-induction of the dynamometer by the bridge method and computed the value of cosine θ which we found to be .999.

To get at the value of the angle φ we connected the primary of a transformer containing no iron to one coil of a dynamometer, and the secondary to the other. The secondary E. M. F. in this case is 90° behind the primary current. When the dynamometer coil alone was in this secondary circuit there was a deflection to the right indicating a lag due to the self-induction of the coil itself. When the resistance of the body was put in series with it the deflection was to the left indicating a lead. As was to be expected in the case of an electrolyte, this angle of advance was found to diminish as the E. M. F. increased. Computed on the assumption that the resistance of the body is 1500 ohms, the results were :

Angle of Advance.	E. M. F.
10°45'	2.16
7°45'	2.70
6°00'	3.53

When the dynamometer is in series with the body the angle of advance of current ahead of total E. M. F., as computed from the largest one of these figures above, is $4^\circ 30'$. This angle has the cosine .997. So we find that the correction $\frac{\cos \varphi}{\cos \theta}$ may be neglected.

As far as these results go, they show that the resistance measured with direct currents is larger than when measured with alternating currents ; and that with the alternating currents it is independent of the voltage.

The ordinary fall of potential method with direct current, which has been shown by Ayrton¹ to apply to electrolytes, was used for the remainder of the work. The current was measured by means of a Weston standard voltmeter and the drop of potential with a condenser and galvanometer. Platinum foil strips fastened to the points between which the resistance was to be measured, served as the terminals of the condenser. With the terminals in place, a reading of the condenser discharge was made with no current through the body. If this was found to be large, the strips of foil were taken off and heated to redness and again put back. If small, the readings were next taken with the current flowing ; then another reading without a current. The mean of the readings with no current subtracted from the reading with a current flowing gave the fall of potential required.

The table below is an example of the method. The current came in through the fingers as in the previous experiment, and the fall of potential was measured from wrist to wrist.

¹ See Ayrton and Perry, Proceedings of Physical Society, 1883, p. 303.

Current.	Deflection.	Deflection due to fall of Potential.	Volts.	Resistance.
.0	-2			
.00226	96	97.5	1.404	628
.00221	95			
.0	-2			
.00226	95			
.00226	101	100.5	1.447	637
.0	-3			

Three other sets of readings with 0008 ampere gave 629, 646, and 604 as the resistance. In the same way from the left jar of liquid to the left wrist, the figures obtained were 370 and 353. From the right wrist to the liquid, the results were 337 and 349. Adding the mean values we get 1334 ohms as the resistance from one jar to the other. This is less than the results obtained in the other way, and is probably due to the fact that the hands were not thoroughly dry above the surface of the liquid.

In taking readings from the solution to the body a platinum wire projecting from a glass tube was used instead of the platinum foil. The results were seldom as satisfactory as those obtained from one part of the body to the other. From the right wrist to the elbow the resistance was found to be 200 ohms. From the wrist to the end of the shoulder blade, it is 267. From shoulder to instep it is 291. These last figures are independent of the skin resistance which is inversely proportional to the area, and varies with the degree of moisture and the nature of the electrode.

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