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EXTERNAL BIOELECTRODES: A BATTERY SUBSTITUTE FOR BIOLOGICAL TELEMETRY SYSTEMS

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Abstract

The power output of various electrode pairs, in saline and on the skin, have been reported. Probable reasons for variations in the power output have been included. A basic minimal power output for the Mg - Ag electrode pair has been established and found to be more than adequate for telemetry systems. Electrodes have proved to be reliable over long periods of time without special maintenance.

Introduction:

For the past year experiments have been conducted in this laboratory for the purpose of determining the amount of electrical power available from various dissimilar metals placed on the skin. These studies were designed to determine the best materials to be used as a power source for electronic devices such as telemetry systems. Such a system could include the transmission of voice, EKG, or other physiological functions. The electrodes that are being studied now are called the power electrodes and would be used to generate the carrier signal. Another electrode leading into the modulating circuit would pick up transient electrical events in the body such as changes in galvanic skin response, EKG, EEG, or similar signals. The development of miniaturized or micro-miniaturized electronic modules, which require small quantities of electrical power, are especially well adapted for use of this type of power source.

Present telemetry systems are powered by batteries which have to be periodically recharged. Also, these batteries are prone to sudden failure, therefore, extra batteries must be taken along to guard against this contingency.

In view of these facts, the replacement of conventional batteries by electricity obtained directly from man would appear to be advantageous.

This has been accomplished by attaching two electrodes to the wrist where it is possible to obtain a continuous output of usable electrical energy. This electrical energy has been used for powering a transmitter which is designed to transmit cardiac and respiratory data.

The electrodes, in their present form, are fitted on the under side of one watch band, are reliable and are capable of functioning for years.

In the beginning, emphasis was placed on the development of a biological fuel cell for space use. This work was conducted in part, under NASA contract. In this phase of the work, a GE fuel cell was used to study the mechanism by this system was found to be dependent upon a double catalytic reaction. First, the intracellular enzymatic reactions necessary to change the glucose from a non-fuel to a fuel and secondly, a physico-chemical oxidation of the fuel at the active sites on the platinum black electrode which released electrons to the external circuit (1,2).

The fact that extra cellular metabolites were found to be fuel cell active led to the idea that a useable quantity of electricity may be possibly derived from intact mammals.

In effect, the animal is analagous to the fuel cell in that the ingested food acts as a fuel, oxygen and electrolytes are present, and, the whole body acts as a volume conductor. Therefore, if two electrodes were placed in the body in appropriate areas where a fairly large difference in oxidation reduction potential existed a current would be expected to flow. Further, the quantity of this electrical energy may be enhanced by the use of a catalytically active electrode in one of the antomical loci (3,4,5).

This concept was tested by implanting electrodes in rats, and determining the power available as a function anatomical position. Electrical measurements were made by implanting two electrodes in different parts of the animal. Areas tested were the intestine, peritoneal cavity, subcutaneous, muscle, etc. (6). In subsequent experiments, a calculated output of 100 micro watts was obtained when a stainless steel-platinum black electrode pair was used.

These data were submitted to an electronics engineer for evaluation as regards to the usefullness of such small quantities of electrical power. As a result, a 500 KC transmitter was designed which would operate on 0.25 v at 50 micro amps or 12.5 micro watts.

Stainless steel and platinum black electrodes were implanted in the subcutaneous and peritoneal half cells respectively and the transmitter was attached. It was possible to power this device for 8-10 hours without any appreciable drop in signal output.

To prove that this energy was dependent upon biological activity, and not just an effect derived from the difference in the electrochemical properties of the electrodes, an animal was sacrificed. The voltage output as observed on an oscilloscope fell steadily after death and the transmitter ceased to operate after 75 minutes. For the past 8 months, additional work has been conducted under a contract from National Aeronautics and Space Administration.

These data have been reported in quarterly reports submitted to NASA, Ames, Palo Alto, California (7a,b,c).

Implanted electrodes are especially ideal for use in experimental animals or in humans where exceptional circumstances warrent surgical implantation (heart pacers, etc.)

However, because of the surgical procedures required, these electrodes could not be used routinely in manned space flights. Therefore, it was clear that external electrodes had to be developed before bioelectricity obtained from humans could be put to use without resorting to surgical procedures.

In the past, most investigators have been interested in studying bioelectric potentials in order to understand basic electro physiological reactions. They have therefore gone to great lengths to be sure the signals recorded were not affected by the electrodes being used.

This method which is exactly opposite, takes advantage of the body as a volume conductor and enhances the output by the deliberate use of dissimilar electrode material.

Experimental

I Method for Evaluation of Electrode Pairs in Saline

The various metals used in this study were cut from large pieces of stock into three sizes; 4, 9, and 16 centimeters square. Electrode pairs of the same size were immersed in 0.9% saline and polarization curves were obtained in the following manner: Wire leads attached to the immersed electrodes were plugged into a decade resistance box. The resistance box was connected to a recording volt meter. Data for polarization curves were obtained by a step wise drop in the resistance in the circuit which resulted in a concommitant voltage drop. These values were used to calculate the number of amperes and then to plot the polarization curves. The power output was obtained by using the above data. This procedure was repeated with electrode sets of different sizes.

Charts No. 1 and No. 2 show the maximum power output averages for the polarization curves. These data were used as a baseline for comparison with values obtained when the same set of electrodes were placed on the skin. The results show that current density is affected by the area of the electrodes but is not strictly linear.

II Methods for Evaluation of Electrode Pairs on the Skin

Electrode pairs of the same size were covered with electrode paste and placed opposite each other on the wrist of a human. These electrodes were held in place by rubber EKG bands. Metal tips protruding through the bands were used as an attachment for the leads that were plugged into a decade resistance box. Data for polarization curves were obtained in the same manner as described above. For each pair of electrodes, of a particular size, this procedure was repeated on three different individuals of both sexes (total 9 sets of data).

Charts No. 3 and No. 4 show the amount of power obtainable from various electrode pairs and sizes. The data indicate that the current was generally dependent upon the area of the electrode but was not at all linear. These variations may have been caused by poor contact with the skin.

Comparison of the charts show the power output for any one set of electrodes followed the same order in power output that was observed in the saline experiments. The lower values obtained from the skin may be attributed to a higher internal impedance which is a function of the skin resistance and electrical contact.

III Comparison of Anatomical Loci

Initial experiments showed no appreciable differences in power output values when the electrodes were placed on the same arm or on different arms or on any other part of the body i.e., arm and leg. Subsequent experiments conducted under more controlled conditions indicate that minor variations existed.

Three electrode pairs, the negative Mg electrode (16 cm^2) and the more positive electrodes Brass, SS-310 and Cu (16 cm^2), were chosen because they gave the highest power output in previous experiments. Each pair of electrodes was covered with electrode paste and placed at different sites on the extremities, i.e., the same arm, different arms or an arm and a leg. Polarization curves were run in the same manner as described before in I.

Chart No. 5 shows the location of the electrode pairs and peak power output values obtained on a male and a female. Data presented in this chart shows that the best arrangement of the electrodes for convenience and high output was on the same arm one inch apart. Some of the other sets gave higher power output (in the case of the male) but wearing electrodes on an arm and a leg for even short periods of time proved to be very cumbersome. Therefore, in most of the following experiments, the standard procedure was to use the Mg - Brass electrode pair on the wrist 1 inch apart.

IV Elimination of direct electrode-skin contact

During the extensive testing of the Mg - Brass electrode pair it was noted that the Mg electrode caused irritations to the skin. Therefore, it was decided that the electrodes should be removed from direct contact with the skin. Attempts to establish an indirect electrode-skin contact, yet retain a direct electrical contact, resulted in the following adaptations. First, a 2 cm thick gasket of silicone rubber was fixed around the periphery of both electrodes. The space between the electrode surface and the skin was filled with electrode paste. Polarization curves were very much lower in comparison with the direct electrode-skin contact values. Next paper toweling and felt were cut into squares slightly larger than the electrodes. These materials were saturated with NaCl solution and placed between the electrodes and the skin. Values obtained from these experiments were compariable to the power output obtained with the gaskets. Finally, desirable electrical contact with no apparent skin irritation was effected by placing pieces of gauze treated with NaCl solutions or electrode paste at the skin-electrode interface.

Chart No. 6 gives peak power output values for gauze saturated with NaCl solutions and Chart NO. 7 gives values for gauze pads treated with electrode paste.

Attempts to repeat these experiments resulted in appreciable variations in the polarization curves. Using the Mg - Brass electrode pair (16 cm^2 patches) and gauze saturated with NaCl solutions as electrolyte, polarization curves were run in triplicate on various individuals. Before the start of each curve the surfaces of the electrodes were cleaned (Mg was filed) and the skin was thoroughly rinsed off to remove residues of electrolyte from previous experiments. Initially the corrosion and tarnishing of the electrodes was considered to be a variable, however, a series of experiments showed that there was no significant change in power output when the electrodes had not been cleaned for nearly a year.

Chart No. 8 shows the variations encountered among three individuals having polarization curves run on them under exactly the same conditions. Chart No. 9 shows the variation between two individuals and also shows how an individual himself may vary. Data on the male shows variation among 3 values obtained in the morning and again for the three values obtained in the afternoon. (continually rising).

Similar experiments using the gauze pads treated with electrode paste gave the same results as above. Therefore, the following new adaptations were devised and tested in an attempt to determine the causes of these variations. First the geometry of the electrodes was altered, because it was felt that watchband type electrodes (8×2 cm = 16 cm^2) would fit the contours of different arms more adequately than the square patches ($4 \times 4 = 16$ cm^2) and therefore afford better contact. Tests have shown that in the case of females (smaller wrists) this adaptation has lead to higher power output. Secondly, a silver electrode was substituted for the Brass electrode because it was felt that a pure metal electrode would be more desirable to work with in these studies than an alloy. Thirdly, it was felt that the cleaning of the Mg electrode by filing might actually be changing the surface area significantly. Therefore, fine sandpaper was used to polish the surface of the electrode to insure constant surface area. The location of the electrodes on the arm was never changed i.e., the Mg was never placed where the Ag electrode had been previously, etc. Lastly, the amount of electrolyte used was measured and kept constant. The use of these new adaptations in conjunction with the techniques described before, did not however, appreciably control the variation.

The possible existence of some type of equilibrium between the electrodes, skin, and electrolyte was investigated. An invariant series of data would be expected if some type of equilibrium did exist. A new protocol was developed to study this hypothesis. The arm was washed in warm water to remove oil or soap and perhaps open the pores. Two mls of electrode paste were applied to the areas where the electrodes were to be placed and rubbed into the skin for a few minutes. Gauze pads the same shape of the electrodes but a little larger were placed over these areas; the excess paste was absorbed by these pads. The electrodes were placed over the gauze strips and a polarization curve was run. After the curve was run only the electrodes were removed, cleaned and nothing else was disturbed. The electrodes were replaced making sure that no electrical connection exists between them except skin itself. Over a period of 1 hour four more curves were run. This interval was arbitrarily chosen as the amount of curves necessary to reach equilibrium. Assuming equilibrium has been reached, the electrolytic media was rejuvenated by adding 1 ml of electrode paste to each area. Three more curves were run as before and their results were compared for constancy.

Chart No. 10 shows the trends for three days on two individuals (male and female). Data given for the first day show the entire trend i.e., peak values for the five curves before equilibrium and then for the three thereafter. Data for the second and third day show peak values only for the three curves run after equilibrium.

A similar study using gauze pads saturated with 10% NaCl solution gave the same trend but the power output values were much lower. These data are presented in Chart No. 11.

The effect of dissolved Mg salts on equilibrium in this system was also investigated. Experiments in which this mixture was placed under the Mg electrode (plain electrode paste under the Ag) and then under the Ag electrode (plain paste under Mg) and then under both electrodes showed no apparent affect on the equilibrium time.

V Investigation of other possible Electrolytes

In order to see if another electrolyte bedides NaCl solution might increase the power output of the electrodes, gauze pads were saturated with various concentrations of KCl, Boric acid (weak acid), and NaHCO3 (weak base) solutions and tested with the electrodes. Power output values indicated that none of these solutions gave any increase in power when compared with NaCl solutions.

Additives to plain electrode paste were tested to see if they increased power output. Known amounts of crystalline KCl, crystalline NaCl and a 25% solution of NaCl were added to plain electrode paste. Gauze pads treated with these mixtures were tested with the electrodes. Polarization curves were run and the power output observed was much less than obtained with plain electrode paste.

An attempt to use skin lotions with additives as the electrolytic media was tested. Measured amounts of crystalline KCl and crystalline NaCl and a solution of 25% NaCl were mixed with the skin lotion, gauze pads treated with these mixtures were tested with the electrodes. Again polarization curves indicated that these systems did not appreciably increase power output when compared with plain electrode paste.

Discussion

Discrepancies in power output as a function of electrode area have been observed in saline as well as on the skin. For instance, Chart 2 shows that the 9 cm^2 Fe - Brass electrode pair as being higher than the 16 cm^2 (1,000 u.a. vs. 650 u.a.). This variation may be caused by polarization of the electrode or by connection of the alligator clips with the system via the salt solution. Every precaution was taken to eliminate this possibility but the electrolyte may have, by capillary action, formed an invisible bridge. This would result in the measurement of a mixed potential.

Chart 4 shows some values for electrodes on the wrist. For example, 4 cm^2 Pt - Fe electrodes gave more power than the 9 cm^2. Further the 9 cm^2 was higher than the 16 cm^2 (58 u.a., 27 u.a., 20 u.a. respectively). Variations in contact with the skin via the electrolyte could produce these discrepancies. These variations were essentially eliminated by using a watch strap type of electrode.

The power values for some electrode pairs, charts 1 through 4, were so low that no data were reported.

Skin irritation was eliminated by the use of a gauze patch between the skin and the electrode. The irritation that was observed earlier was ascribed to small nicks in the skin which were produced by multiple application of these electrodes to the same area. The burning sensation was probably caused by the contact of electrolyte with these denuded areas.

Recent studies, using an Mg - Ag electrode pair, were conducted to determine the cause of variation in power output. It was possible to obtain relatively large variations from the same person on the same day using the same electrodes. Experiments showed that these variations still occurred whether the electrodes remained in place for 15 minutes or one hour.

As can be seen from Chart 10 and Chart 11, it was possible each day to reach equilibrium with one particular individual. At this point polarization curves run on males or females became constant. However, it was noted that these constant values varied from day to day for an individual and there was variation among the data obtained from individuals (male or female) tried the same day. The reasons why the constant values obtained from a pair of electrodes used on the same individual under the same conditions (equilibrium, etc.) should vary from day to day is a matter of speculation at this time. Since we are assuming that we have a system in equilibrium when the curves and power output become constant, the variation noted seems to point to changes in the equilibrium. Osmotic pressures present in the tissue, which could either facilitate or inhabit the absorption of the electrolyte into the skin and hence shift the equilibrium one way or another, are certain to vary from day to day. A daily variation in the quantity of the cornified squamous epithelium may have also influenced the absorption of the electrolyte through the skin and therefore effect the power output. These ideas in conjunction with the physiological differences that exist between individuals' skin are probable explanations for variations observed in these studies.

However, at any rate it has been established that 120 µ.a. at 0.85 volts can be obtained from electrodes of Mg and Ag after a years usage. Over this period of time these electrodes were never cleaned. The above values are essentially the same as for the cleaned electrodes.

A power output of 120 µ.a., 90 µ.w. is constant and is certainly adequate for powering a telemetry system. Mr. T. Fryer, NASA, Ames (ref. 8), states that he has developed a telemetry system which uses only 10 µ.w. Values obtained from external electrodes far exceed this requirement.

Problem Areas

1. Variation in power output still exist but has been considerable stabilized.

2. Work on the telemetry system has bogged down due to the unavailability of the electronics engineers. Funding for this project was limited therefore, it was impossible to retain more knowledgeable personnel.

Future Work

1. Additional studies concerning the causes of variation in power output may be extended. On the other hand, a basic, reliable power output range has been established which far exceeds minimum requirements for a telemetry system.

2. The development of a telemetry system using this principle should be developed under a joint contract with Hahnemann Medical College and some <u>professional</u> electronics firm. This system should be designed to telemeter voice, ECG and respiration.

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Chart 1
Maximum Power Output of Electrodes Immersed in 0.9% Saline

+ Metal	- Metal	Size	OCV	Ohms	Volts	Micro Amps	Micro Watts
Ag	Al	9 cm^2	.58	400	.24	600	140
		16 cm^2	.58	200	.26	1300	340
Ag	Brass	9 cm^2	.18	2K	.06	30	1.8
		16 cm^2	.17	4K	1.3	32	4.2
Ag	Cu	9 cm^2	.10	400	.03	75	2.25
		16 cm^2					
Ag	Mg	9 cm^2	1.01	1K	.84	840	705
		16 cm^2	1.40	800	.83	1037	860
Ag	Pt	9 cm^2					
		16 cm^2					
Ag	St. Steel	9 cm^2	.20	20K	.06	3	.18
		16 cm^2	.28	30K	.26	8.7	2.3
Brass	Mg	9 cm^2	1.40	1K	.98	980	960
		16 cm^2	1.44	800	.94	1170	1099
Cu	Mg	9 cm^2	1.46	2K	1.10	550	605
		16 cm^2	1.44	400	.93	2325	2162

Chart 2

Maximum Power Output of Electrodes Immersed in 0.9% Saline

+ Metal	- Metal	Size	OCV	Ohms	Volts	Micro Amps	Micro Watts
Brass	Al	9 cm^2	.58	400	.24	600	140
		16 cm^2	.58	200	.26	1300	340
Cu	Al	9 cm^2	.59	100	.15	1500	225
		16 cm^2	.63	100	.14	1400	196
Al	Fe	9 cm^2	.35	30K	.34	11	3.8
		16 cm^2	.34	30K	.33	11	3.6
Pt	Al	9 cm^2	.78	800	.32	400	12.8
		16 cm^2					
St. Steel	Al	9 cm^2	.47	1K	.14	140	19.5
		16 cm^2	.58	1K	.17	170	28.5
Cu	Brass	9 cm^2	.059	1K	.026	26	.68
		16 cm^2	.055	1K	.026	26	.68
Brass	Fe	9 cm^2	.87	400	.40	1000	400
		16 cm^2	.89	800	.52	650	340
Pt	Brass	9 cm^2	.20	8K	.09	11.4	1.07
		16 cm^2					
Brass	St. Steel	9 cm^2	.04		.1	5	
		16 cm^2	.11	20K	.051	2.5	.13
Fe	Mg	9 cm^2	.62	60	.16	2667	426
		16 cm^2	.54	8K	.52	65	34
Pt	Fe	9 cm^2					
		16 cm^2					
Ag	Fe	9 cm^2					
		16 cm^2					
St. Steel	Mg	9 cm^2	1.32	1K	.68	680	462
		16 cm^2	1.22	1K	.68	680	462
Cu	Fe	9 cm^2	.95	200	.33	1650	545
		16 cm^2	.92	400	.45	1125	506
Cu	St. Steel	9 cm^2	.08	30K	.06	2	.12
		16 cm^2	.08	10K	.04	4	.16
Pt	St. Steel	9 cm^2	.17	20K	.06	1	.02
		16 cm^2					
St. Steel	Fe	9 cm^2	.71	100	.07	700	49
		16 cm^2	.95	400	.35	875	306
Pt	Mg	9 cm^2	1.52	1K	.78	780	608
		16 cm^2					

Chart 3

Power Output of Electrodes on Wrist with Electrode Paste at the electrode-skin interface

	+ Metal	- Metal	Size	OCV	Ohms	Volts	Micro Amps	Micro Watts
1)	Ag	Al	4 cm^2	.44	30K	.21	7	1.4
			9 cm^2	.40	8K	.14	18	2.5
			16 cm^2	.37	10K	.19	19	4
2)	Ag	Brass	4 cm^2	.15				
			9 cm^2	.18	20K	.08	4	.32
			16 cm^2	.18	8K	.10	13	1.3
3)	Ag	Cu	4 cm^2	.24	10K	.10	10	1.0
			9 cm^2	.22	8K	.10	13	1.3
			16 cm^2	.24	4K	.11	28	3.0
4)	Ag	*Zn	4 cm^2	.56	30K	.41	14	6
			9 cm^2	.59	6K	.26	65	17
			16 cm^2	.60	8K	.37	47	17.5
5)	Ag	Mg	4 cm^2	1.40	20K	.12	36	26
			9 cm^2	1.45	8K	.59	67	36
			16 cm^2	1.35	4K	.46	115	53
6)	Ag	Pt	4 cm^2	.11	10K	.06	6	.36
			9 cm^2	.11	10K	.07	7	.49
			16 cm^2	.16	4K	.05	12	.60
7)	Ag	SS-310	4 cm^2					
			9 cm^2	.22	10K	.10	10	1.0
			16 cm^2	.20	8K	.09	13	1.1
8)	Al	Mg	4 cm^2	.77	20K	.40	20	8
			9 cm^2	.75	20K	.44	22	10
			16 cm^2	.81	8K	.46	57	26
9)	Brass	Mg	4 cm^2	1.45	20K	.64	32	20
			9 cm^2	1.45	10K	.67	67	45
			16 cm^2	1.46	10K	.85	85	72
10)	Cu	Mg	4 cm^2	1.44	8K	.69	86	59
			9 cm^2	1.45	8K	.65	81	53
			16 cm^2	1.46	10K	.74	74	55

* galvanized iron

Chart 4

Power Output of the Electrodes on Wrist with Electrode Paste at the Electrode-Skin Interface

+ Metal	- Metal	Size	OCV	Ohms	Volts	Micro Amps	Micro Watts
Pt	Mg	4 cm^2	1.13	4K	.50	125	62
		9 cm^2	1.24	4K	.59	147	87
		16 cm^2	1.33	8K	.71	89	63
SS-310	Mg	4 cm^2		10K	.54	54	29
		9 cm^2	1.44	10K	.58	53	34
		16 cm^2	1.33	2K	.33	165	54
Brass	Al	4 cm^2	.56	10K	.24	24	5.8
		9 cm^2	.55	8K	.36	45	16
		16 cm^2	.53	4K	.20	50	10
Brass	Pt	4 cm^2	.12				
		9 cm^2	.09				
		16 cm^2	.09				
Al	Fe	4 cm^2	.21				
		9 cm^2	.18				
		16 cm^2	.25				
Brass	Fe	4 cm^2	.75	8K	.49	61	30
		9 cm^2	.75	8K	.30	37	11
		16 cm^2		4K	.35	89	31
Cu	Fe	4 cm^2	.77	4K	.29	73	26
		9 cm^2	.78	4K	.36	90	32
		16 cm^2	.81	4K	.48	128	58
Fe	Mg	4 cm^2	.55	4K	.29	76	21
		9 cm^2	.59	4K	.25	62	15
		16 cm^2	.57	4K	.31	79	24
Pt	Fe	4 cm^2		20K	.34	17	58
		9 cm^2		8K	.46	57	27
		16 cm^2		8K	.40	50	20

+ Metal	- Metal	Size	OCV	Ohms	Volts	Micro Amps	Micro Watts
SS-310	Fe	4 cm^2	.61	20K	.30	15	4.5
		9 cm^2	.64	10K	.21	21	7.3
		16 cm^2	.74	10K	.27	27	7.3
SS-310	Al	4 cm^2	.48	20K	.23	12	2.7
		9 cm^2	.53	10K	.22	22	4.8
		16 cm^2	.44	10K	.24	24	5.8
Brass	SS-310	4 cm^2	.12				
		9 cm^2	.20				
		16 cm^2	.08				
Cu	SS-310	4 cm^2	.14				
		9 cm^2	.16				
		16 cm^2	.08				
Pt	SS-310	4 cm^2	.09				
		9 cm^2	.14				
		16 cm^2	.17				
Cu	Al	4 cm^2	.58	8K	.20	25	5
		9 cm^2	.60	10K	.26	26	6.8
		16 cm^2	.57	4K	.20	50	10.0
Cu	Brass	4 cm^2	.02				
		9 cm^2	.06				
		16 cm^2	.02				
Cu	Pt	4 cm^2	.18				
		9 cm^2	.14				
		16 cm^2	.11				

Chart 5

Comparison of Anatomical Loci

Location	Electrode Pair	Male				Female			
		Ohms	V.	µ.a.	µ.w.	Ohms	V.	µ.a.	µ.w.
Both on same arm, 1 inch apart	Mg - Brass	5K	.66	132	87	5K	.70	140	98
	" - S.S.	5K	.54	108	58	10K	.58	58	34
	" - Cu	10K	.72	72	52	10K	.82	82	67
Both on same arm, sandwiched	Mg - Brass	50K	.62	12.4	7.7	10K	.70	70	49
	" - S.S.	50K	.72	14.4	10.4	20K	.54	27	14.6
	" - Cu	20K	.70	35.0	24.5	20K	.58	29	16.8
Mg on left arm, others on right arm	Mg - Brass	10K	.58	58	33.5	50K	.50	10	5.0
	" - S.S.	10K	.59	59	35.0	20K	.62	31	13.9
	" - Cu	5K	.66	132	87.1	20K	.76	38	29.0
Mg on left arm, others on left leg	Mg - Brass	5K	.74	148	110	20K	.72	36	25.6
	" - S.S.	5K	.54	108	58.4	20K	.66	33	21.6
	" - Cu	2K	.54	270	146	20K	.90	45	40.1
Mg on left arm, others on right leg	Mg - Brass	5K	.60	120	72	50K	.80	16.0	12.8
	" - S.S.	5K	.51	102	52	20K	.62	31.0	19.1
	" - Cu	5K	.81	162	132	20K	.81	40.5	32.7
Both on the same leg, 1 inch apart	Mg - Brass	100K	.75	7.5	5.6	100K	.45	4.5	2.02
	" - S.S.	20K	.59	29.5	17.4	20K	.64	32	20.1
	" - Cu	20K	.87	48.5	42.2	20K	.46	23	10.6

Chart 6

Gauze Pads Saturated with NaCl Solutions

Concentration of NaCl solv.	Ohms	Volts	µ.a.	µ.w.
5%	5K	.78	156	122
10%	2K	.70	350	245
15%	2K	.76	380	288
20%	2K	.85	425	361
25%	11K	.62	620	385

Chart 7

Gauze Pads Treated with Electrode Paste

Conditions	Ohms	Volts	µ.a.	µ.w.
electrode paste between electrodes (no gauze)	5K	.80	160	128
electrode paste on electrode, dry gauze, no paste on arm	2K	157	285	162
gauze saturated with paste	10K	.74	74	55
electrode paste on arm, dry gauze, paste on electrode	2K	.65	325	212
electrode paste on arm, dry gauze, no paste on electrode	5K	.60	120	72

Chart 8

Variation Among Three Individuals

Gauze saturated with 5% NaCl

Curve	Male				Female				Female			
	Ohms	v.	µ.a.	µ.w.	Ohms	v.	µ.a.	µ.w.	Ohms	v.	µ.a.	µ.w.
1	5K	.57	114	65	50K	.60	12	7.2	20K	.56	28	15.7
2	5K	.57	114	65	50K	.72	14	10.4	100K	.62	6.2	3.9
3	5K	.57	114	65	50K	.64	13	8.2	20K	.70	35	24.5

Chart 9

Variation (Cont.)

Gauze saturated with 10% NaCl (morning)

Curve	Male				Female			
	Ohms	Volts	µ.a.	µ.w.	Ohms	Volts	µ.a.	µ.w.
1	5K	.42	84	35	50K	.66	13.2	8.6
2	5K	.63	126	79	50K	.72	14.4	10.3
3	5K	.65	130	84	20K	.54	27.0	14.5
						(afternoon)		
1	5K	.51	102	52	10K	.37	37	18.7
2	5K	.76	152	116	20K	.54	27	14.6
3	2K	.56	280	157	20K	.56	28	15.7

Chart 10

Illustration of Equilibrium

Gauze pads saturated with electrode paste

Day	Curve	Male				Female			
		Ohms	Volts	µ.a.	µ.w.	Ohms	Volts	µ.a.	µ.w.
1st	1st	5K	.81	162	131	20K	.70	35	25
	2nd	5K	.75	150	113	10K	.70	70	49
	3rd	5K	.71	142	102	5K	.62	124	77
	4th	5K	.67	134	90	10K	.66	66	44
	5th	5K	.61	122	74	10K	.68	68	46
		1 ml paste added				1 ml paste added			
	6th	5K	.69	138	95	5K	.71	142	101
	7th	5K	.69	138	95	5K	.78	156	121
	8th	5K	.70	140	90	5K	.75	150	112
2nd	6th	10K	.84	84	71	5K	.82	164	135
	7th	10K	.84	84	71	5K	.82	164	135
	8th	10K	.84	84	71	5K	.82	164	135
3rd	6th	2K	.54	270	146	5K	.80	160	128
	7th	2K	.54	270	146	5K	.76	152	115
	8th	2K	.55	275	151	5K	.74	148	110

Chart 11

Gauze pads saturated with 10% NaCl solution

Day	Curve	Male				Female			
		Ohms	Volts	µ.a.	µ.w.	Ohms	Volts	µ.a.	µ.w.
1st	6th	5K	.67	134	90	10K	.66	66	44
	7th	5K	.67	134	90	10K	.70	70	49
	8th	5K	.65	130	84	10K	.74	74	59
2nd	6th	5K	.57	114	65	10K	.56	56	32
	7th	5K	.62	124	77	10K	.62	62	38
	8th	5K	.62	124	77	10K	.68	68	46