The integration of F and G when $m < 1$ is troublesome, but when m is sufficiently small, we may without much error neglect G, and integrate F from 0 to $\pi/2$.

$$\frac{a^5}{2^5}\int_0^{\pi/2} c(c-m)^4 \log\frac{c+m}{c-m}\,d\theta = \frac{a^5 m}{2^4}\int_0^{\pi/2} c^4\left(1 - 4\frac{m}{c} + \frac{19}{4}\frac{m^2}{c^2} - \frac{16}{3}\frac{m^3}{c^3} + \ldots\right)d\theta$$

$$= \frac{a^5 m}{2^4}\left[\frac{3}{16}\pi - \frac{8}{3}m + \frac{19}{16}m^2\pi - \frac{16}{3}m^3 - \ldots\right] \ldots\ldots\ldots (\mathrm{M}).$$

Adding (E) and (M) we obtain

$$\frac{9}{8}\pi^2 a^2 m^2 \frac{f^2\mathrm{B}^2 10^{-16}}{\rho} = 11\cdot1\ a^2 m^2 \frac{f^2\mathrm{B}^2 10^{-16}}{\rho}.$$

"On Skin Currents.—Part III. The Human Skin." By Augustus D. Waller, M.D., F.R.S. Received March 17,—Read April 24, 1902.

(From the Physiological Laboratory of the University of London.)

The purport of the following observations was to examine on human skin the electrical reactions described in previous communications in the case of frog's skin, and in that of the cat's skin.

The Main Facts.—The phenomena are in the main similar under similar conditions, viz., in the case of a freshly removed healthy skin obtained from the operating theatre, the normal current is always ingoing, and the normal response is always outgoing.*

In a series of observations—with values noted for an ingoing current of between 0·0020 and 0·0200 volt—the response has appeared to be quite independent of the magnitude of normal current, and to strong stimulation has usually been from 0·0100 to 0·0400 volt.

As in the case of the frog's skin, the response to single induction shocks has been in the positive or outgoing direction, to both directions of exciting current. Tetanising currents (make and break induction shocks of alternating direction at a frequency of about 60 per sec.) give therefore a summated positive effect. At the outset of my experiments on human skin I encountered doubt and difficulty by reason of the fact that I set myself the difficult problem of determining as far as possible its duration of survival, and by so doing had to deal with cases where a reaction of low voltage is apt to be masked by admixture of polarisation currents. In my experience, healthy skin from the operating theatre, tested within 48 hours after operation, has always manifested indubitable signs of life, and by indubitable I mean a

* 'Roy. Soc. Proc.,' 1901, vol. 68, p. 480; vol. 69, p. 171.

reaction greater than + 0·0050 volt to strong induction shocks of + or − direction.*

Tested by tetanising currents of alternating directions such skin gives to both pairs of directions a similar indubitable positive response of, *e.g.*, 0·0200 to 0·0500 volt.

Moribund skin and skin obtained from the *post-mortem* room, from subjects that have died gradually, have generally afforded doubtful results, and by doubtful results I mean a reaction of variable direction and measured by ten thousandths of a volt.

In all cases the electrodes alone were carefully tested for polarisation, anomalous as well as ordinary, before use and after experiment; the skin was subsequently killed by boiling and the experiment repeated.

The course of events will be best set forth by the detailed account of a single observation.

(Observation 2.) Skin of breast, removed for carcinoma, 1½ hours after operation. The single break induction shock of + and − direction gave the response + 0·0180 + 0·0230, the resistance being 1 megohm.

An Illustrative Observation.—To tetanisation of both pairs of directions the responses were + 0·0440 and + 0·0460. R now ½ megohm. After boiling the resistance was only 50,000 ohms.

The next day the reactions of a fresh piece of same skin to strong single shocks + and − were + 0·0050, + 0·0175 volt. On the 4th day the reactions were + 0·0025 and + 0·0035. In all these cases the positive response was abolished by boiling.

On the 7th day the reactions were doubtful, except in the case of the nipple, where the response to all kinds of excitation was about + 0·0050. In this case the conductivity was increased from 100 to 121 by tetanisation.

Diminution of Resistance.—A remarkable feature noticed in the outset of these experiments was the great diminution of resistance caused by tetanisation. The alteration of resistance was most pronounced in the case of skin which, judging by its response, was most alive; it was far less noticeable in the case of moribund and doubtful skin; it was not apparent at all in the case of skin certainly killed by boiling, as might be expected; however, the resistance of boiled skin was always far below that of the same skin previous to boiling.

All these points will be most clearly apparent by reference to fig. 1.

The noteworthy points are—

(1.) The contrast between the four responses of the living and dead skin.

* Throughout the present paper + signifies "outgoing" and − "ingoing," as regards direction of current through the skin.

(2.) The augmented conductivity of the living skin from (12·5) 25 to 35 in consequence of tetanisation.

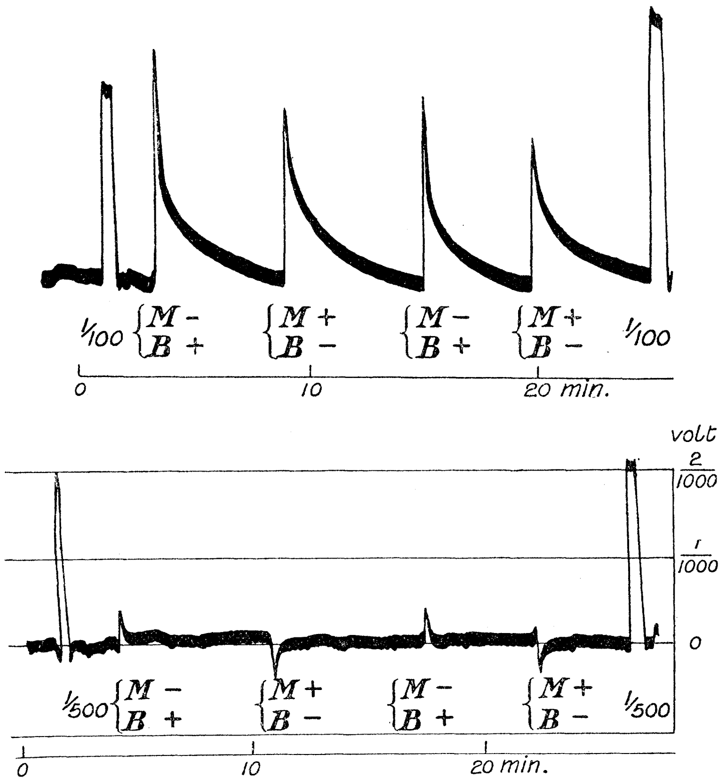


FIG. 1 (Nos. 4199—4200).—Skin of Breast 5 hours after amputation. Tested by tetanising currents for periods of 5 secs. each from a Berne coil at 5000 units, supplied by 8 Leclanché cells. Conductivity at outset of experiment = 5, and calculated resistance = 560,000 ohms. After tetanisation the conductivity was raised to 12·5 (= 224,000 ohms; after further tetanisation it rose further to 25 (= 112,000 ohms), when the record commenced.

A, living.—Conductivity at outset .... = 25
1st response to tetan., m. −, br. +, = + 0·0120 volt.
2nd ,, ,, m. +, br. −, = + 0·0092 ,,
3rd ,, ,, m. −, br. +, = + 0·0100 ,,
4th ,, ,, m. +, br. −, = + 0·0076 ,,
Conductivity at end .... = 35

Skin boiled.—Conductivity .... = 115
1st response to tetan., m. −, br. +, = + 0·0004 volt.
2nd ,, ,, m. +, br. −, = − 0·0004 ,,
3rd ,, ,, m. −, br. +, = + 0·0004 ,,
4th ,, ,, m. +, br. −, = − 0·0004 ,,
Conductivity .... = 115

(3.) The augmented conductivity of the boiled as compared with the living skin—from 35 to 115.

(4.) The unaltered conductivity of the boiled skin—115 before and after tetanisation.

The small deflections seen in the case of the dead skin are such as may be observed with a non-living electrolyte, and are due to polarisation. They follow the direction of the break current, and are due to the fact that the sum of polarisation countercurrents by the series of make currents is greater than the sum of similar effects by break currents.

The four deflections seen in the case of the living skin, do not vary in direction with varying direction of the exciting currents, but exhibit an inequality such that the + (outgoing) deflection after $\left\{\begin{matrix}\text{make } - \\ \text{break } +\end{matrix}\right\}$ is greater than the + deflection after $\left\{\begin{matrix}\text{make } + \\ \text{break } -\end{matrix}\right\}$. This inequality is such as would be produced by the polarisation effect witnessed alone in the dead skin. The four deflections of living skin exhibit a progressive decline, attributable to fatigue.

A similar inequality, attributable to polarisation (but possibly in part due to unequal excitation by the two poles of an exciting current) is witnessed in the outgoing effects of single break induction currents. The + (outgoing) response after an induction current of − direction is greater than the + response after an induction current of + direction. (Fig. 2.)

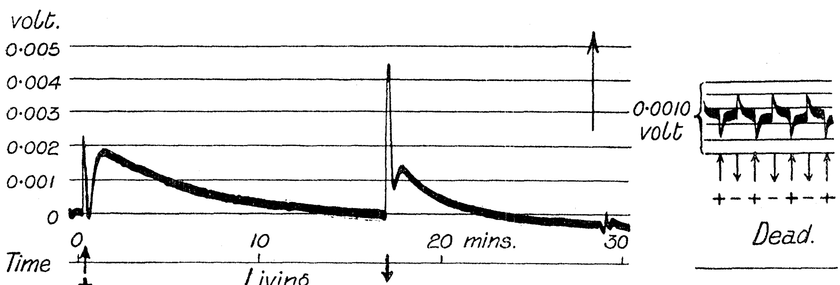


Fig. 2 (4201).—Skin of Breast 8 hours after amputation. *Living.*—Two + responses to single break induction shocks in + and − directions. 8 L. 10,000. *Dead.*—Several − and + effects to + and − shocks, *i.e.*, polarisation. Resistance diminished.

Effect of Previous Excitation.—The response to a particular excitation is greatly influenced by the previous excitation to which the skin may have been subjected. In general, the second of two moderate excitations produces a greater effect than the first, while the second of two strong excitations produces a smaller effect than the first. In the case

of living skin, the influence of single shocks (and still more of alternating currents) is considerable, and must be reckoned with in any estimate of voltage. In, *e.g.*, skin No. VII (*vide* Tabular Summary), the difference between the responses in the two directions of tetanisation at 10,000 units on the second and third days depends on the fact that the order of tests was reversed on the two days. For this reason, in any comparison between the effects of excitation in opposite directions one pair of trials is insufficient: two or more pairs of trials are necessary. In fig. 1, *e.g.*, the result of two pairs of trials is given. In fig. 4204 the decline of voltage is, in reality, much greater than is at first sight apparent, by reason of the augmented conductivity aroused

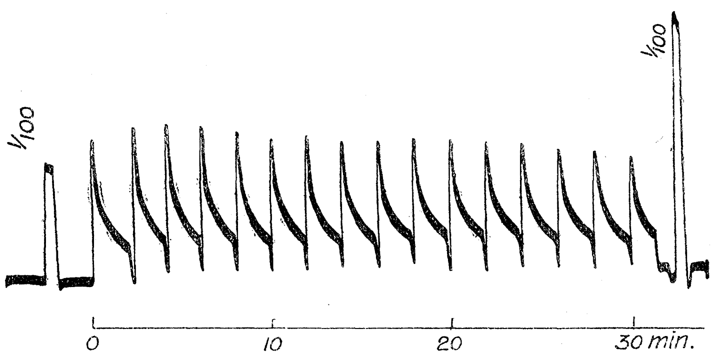


Fig. 3 (4204).—Same skin 22 hours after excision. Series of 16 positive responses to tetanisation for 8 seconds at intervals of 2 minutes. Coil at 1000, supplied by 8 L. Make −, Break +. Gradual decline of E.M.F.; which decline is greater than apparent by reason of increasing conductivity; the latter, as shown by the standard deflections at beginning and end of experiment, has been more than doubled.

by the succession of excitations. For the same reason it is not easy to make satisfactory observations of the variation in strength of response with variation in strength of excitation, even when the mean of successive effects is taken on ascending and descending scales, the influence of fatigue remains obvious, especially if (as ought to be done) the gradual increase of conductivity is taken into account.

For example:—

Skin No. VII. Second Day.

Strength of tetanisation. {make −. break +.}	Deflection.	Conductivity. (Deflection by 0·01 volt.)	Voltage of response.
1000	− 7	50	−0·0014
2000	+ 30	70	+0·0043
4000	+170	130	+0·0130
6000	+280	170	+0·0165
8000	+300	200	+0·0150
10000	+280	230	+0·0122
10000	+240	240	+0·0100
8000	+200	230	+0·0087
6000	+130	220	+0·0059
4000	+ 80	220	+0·0027
2000	+ 30	200	+0·0015
1000	+ 6	180	+0·0003
From which the mean values come out—			
1000	..	..	−0·0005
2000	..	..	+0·0024
4000	..	..	+0·0078
6000	..	..	+0·0012
8000	..	..	+0·0000
10000	..	..	+0·0111

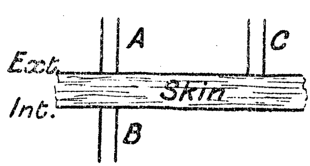
As far as my observations have gone, decline by fatigue has exhibited itself more prominently in the human skin than in the frog's skin. On the other hand, summation of effects has been much less apparent.

Locality of the Reaction.

The blaze currents of human skin arise exclusively from its external epithelial strata, not the most superficial keratinised cells, but the underlying and presumably living cells of the Malpighian layer.

This principal fact is demonstrated in various ways :—

(1.) A piece of fresh skin, put up as figured, is excited through the electrodes A, B, and led off to the galvanometer through A, C, and then through B, C (which are previously compensated before each trial).



There occur in consequence of excitation from A to B and from B to A—

response from C to A no response from C to B,

i.e., the electromotive spot has in each case been situated at or near the external surface A.

(2.) The subcutaneous tissue, and the corium itself, give no response. A slice taken from the sole of the foot and limited to the horny layer gives no response. A slice of skin taken so as to include the Malpighian epithelium gives more or less well-marked response.

And in this last connection I think it worthy of remark that the response is well marked in specimens of skin that did not include any distinct glandular masses. In the pads of the cat's foot *e.g.*, where I had expected to have to reckon with glandular as well as cutaneous epithelium, it was evident on microscopic examination that no glandular tissue was present, but only some scattered ducts belonging to deep-seated glands. The principal active part was clearly the deeply stainable layer of Malpighian epithelium.

The Reaction is Local.—The blaze reaction of the skin is exclusively local, and is not propagated to a distance from the excited spot. And as regards physiological state, it generally happens that closely adjacent portions may exhibit very different degrees of vitality. This has been particularly apparent in the case of mangled skin and of skin involved in cancerous growth. In both these cases it was not difficult to distinguish correctly between skin likely to give a poor reaction and skin likely to give a good reaction. But by reason of such local differences it is not easy to obtain satisfactory instances of declining vitality with lapse of time by taking the reaction of a series of different bits of the same piece of skin; in general, a decline was evident, but with frequent exceptionally low values at an early stage and exceptionally high values at a late stage—*e.g.*, No. VI on the sixth day gave +0·0100 and +0·0150 volt to single shocks—an exceptionally high value at this period.

Nevertheless, it is possible with care to distinguish amid such irregularities the general decline of skin vitality with lapse of time and the individual differences of vitality in different skins of men and animals.

As regards animals, I have, however, made as yet only occasional and unsystematic observations upon cats and rabbits, from which I have provisionally concluded that the skin of man is more enduring than that of either cats or rabbits; that the skin of cats is more resistant than that of rabbits, and that the skins of individual cats and rabbits exhibit considerable differences of endurance according to the state of nutrition at the moment of somatic death.

I have been much astonished, and am still somewhat incredulous, of

my own conclusion with regard to the endurance of human skin. On a healthy skin I have obtained what I take to be signs of life as long as 10 days after excision, and this did not appear to be a longest possible period. I was fully alive to possibilities of fallacy, and expended much care and time upon their experimental exclusion. Whether I have succeeded or not is matter for future investigation. Pathological observations on the human skin in relation to its surgical transplantation to some extent bear out the view that it may survive excision for an extraordinary length of time, especially in a semi-desiccated state and under antiseptic protection. Wentscher* found, *e.g.*, that skin grafts, preserved for 7 to 14 (and in one instance for 21) days, recovered vitality in 3 or 4 days, as indicated particularly by the reappearance of karyokinetic figures.

As regards skin taken from the *post-mortem* room, Schede (quoted by Wentscher) made successful transplantation of skin 12 hours *post-mortem*, but was unsuccessful with 24 hours' old material.

The conductivity of human skin, more especially of fresh human skin, is greatly augmented in consequence of electrical excitation. It is further increased by boiling, and the change occurring gradually in kept skin is of itself sufficient to greatly reduce the original resistance.

Thus, *e.g.*, in skin No. II, examined when I had not yet realised the great influence of previous electrical excitation, and did not therefore measure the resistance of the perfectly fresh skin, the conductivity is increased threefold in consequence of tetanisation, and tenfold in consequence of subsequent boiling.

In a later experiment directed specially to this point, the resistance measured by Wheatstone bridge was originally above 230,000 ohms, falling to below 100,000 ohms in consequence of strong tetanisation.

In my first observations, hardly anticipating any such considerable alterations of resistance, I contented myself with recording a standard deflection of 0·01 volt through the skin (+ electrodes + galvanometer) to see whether or no the resistance was appreciably altered during observation. But I also frequently recorded, for the sake of comparison, the standard deflection of 0·01 volt through a megohm (+ galvanometer) and was therefore able to utilise for the study of alterations of conductivity a considerable body of data directed to other questions. The alterations were indeed so considerable that it was possible without gross error to calculate absolute values of resistance (or conductivity) from the standard deflections recorded at beginning and end of observation. The comparison of such data with data obtained by direct measurement showed that the calculation was permissible. Of course the calculated data are valid only in the case of

* Ziegler's 'Beiträge zur Pathologischen Anatomie und zur Allgemeinen Pathologie,' vol. 24, p. 101, 1898.

the high resistances of unboiled skin, not in that of the low resistances of boiled skin, which, however, are of secondary interest.

The following instance will serve to illustrate the above mode of calculation :—

Skin No. II. 5 hours after excision. Galvanometer + electrode resistance = 20,000 w. Two or three preliminary tests made.

	Defl. by 1/100 volt.	Resistance.
At outset	5	540,000
After four periods of tetanisation	25	92,000
After four further periods (Plate 4199)	35	60,000
After boiling	115	? 4,500
After four further periods (Plate 4200)	115	? 4,500

(Defl. by 1/10 volt through 1 megohm = 26.)

and is (with other data) sufficient proof of the statement that fresh skin has a resistance to be measured in hundreds of thousands of ohms, tetanised skin a resistance of tens of thousands, boiled skin a resistance of thousands.

With regard to the cause of this remarkable augmentation of conductivity, we are in presence of two possible alternatives: 1st, a "kataphoric" migration of water; and 2nd, a dissociation of electrolytes.

I do not at present see my way to the sharp discrimination of these two possible factors, and can only bring forward considerations that appear to me to show that the second factor—electrolytic dissociation—is a chief cause of the increased conductivity, although no doubt transport of fluid, and indeed in certain cases rise of temperature may contribute to the effect.

The diminution of resistance is produced in far more marked degree in living skin than in dead skin. It is best produced in consequence of the summated effect of alternating currents; it is evident in consequence of a single strong induction shock. Thus, *e.g.* (Skin IV) an initial resistance of $1\frac{2}{3}$ megohm, was lowered to 1 megohm after two single induction shocks at 10,000, and to $\frac{1}{2}$ megohm after tetanisation at 1000 for two periods of 5 seconds.

Kataphoric alterations of resistance, as described by du Bois-Reymond, are in the sense of an augmentation caused by desiccation at the anode of a strong prolonged galvanic current. And although there can be no doubt that such anodic augmentation has as its counterpart a kathodic diminution of resistance by reason of augmented moisture, it is not *à priori* very probable that the great alteration of skin resistance caused by one or several induction shocks is due to predominant kathodic augmentation of moisture.

On the other hand, I have observed a case, that of the hen's egg, in which induction shocks give a similar considerable increase of conductivity which I find it difficult to understand otherwise than as an effect of water transport from electrode to shell at the anodic side, and from contents to shell at the kathodic side.

I am constrained therefore to leave undetermined the possible influence of kataphoric action on skin resistance until I shall have found means of investigating the phenomenon further.

Alterations of temperature produce alterations of resistance of the skin as of any moist conductor, viz., augmentation of resistance with lowered temperature, and diminution of resistance with raised temperature. In the case of the *living* skin (as in that of some other living tissues) I have witnessed at the moment of congelation and on subsequent thawing, two well-marked effects that appear to be most significant of a phenomenon of dissociation. At a critical temperature (−4° to −6° of the cooling chamber) a sudden electromotive discharge takes place, attributable to the sudden excitation or explosion of living matter in the act of congelation. Subsequently, on return of the frozen skin to the original temperature, the resistance is very much reduced, a change which is attributable to mechanical or chemical dissociation of the previously frozen tissue-elements.

Thus, *e.g.*, in Experiment 4209 the resistance of the skin (corrected for electrode resistance) at 18° was 150,000 ohms before congelation,

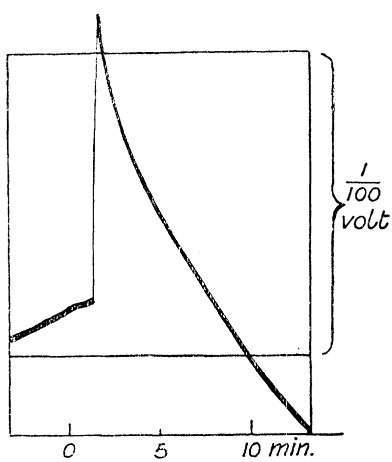


FIG. 4 (4209).—Skin No. III, 2nd day after excision. Skin gradually cooled by surrounding the skin-chamber with a freezing mixture. Sudden electromotive discharge (outgoing current) at a temperature of −6° inside the skin-chamber. Before freezing, the + responses to + and − single induction shocks were +0·004 and +0·008 volt. After freezing, the + responses were absent, being replaced by small − and + polarisation effects. On recongelation no second discharge was observed.

and after congelation 50,000 ohms at 14°. At the temperature of − 6° of the cooling chamber a sudden electromotive discharge of + 0·0080 volt took place. The responses to excitation of + 0·0040 and + 0·0080 previous to congelation, were abolished in consequence of congelation.

Sources of Fallacy—Doubtful Cases.

In ordinary cases (*i.e.*, with healthy skin a few hours after removal from the body) and with ordinary care, the results of experiment are unmistakable, and there is no room for doubt. A clear, positive response of more than 0·01 volt, to single shocks of both directions and to alternating currents of both pairs of directions, is proof that the skin is living.

But at later periods, and in cases of skin obtained from the *post-*

Voltage of Response of Human Skin after Excitation by Induced

	Plate No.	Time.	Single break current.		Tetanisation for 5 seconds by			
			10000.		1000.		5000.	
			+ (outgoing).	− (ingoing).	{make − / break +}	{make + / break −}	{make − / break +}	{make + / break −}
No. I. Skin of amputated leg	4187	3 hrs.	+0·0005	+0·0010	—	—	—	—
	4188	4 ,,	—	—	—	—	—	—
	4189	—	—	—	—	—	—	—
	4190	6 hrs.	+0·0020	+0·0025	+0·0030	—	—	—
	4192	2nd day	+0·0005	+0·0010	+0·0020	+0·0010	—	—
	4193	3rd ,,	−0·0002	+0·0004	+0·0010	nil	—	—
	4194	,, ,,	−0·0001	+0·0001	—	—	—	—
	4195	4th ,,	+0·0005	+0·0010	+0·0010	+0·0020	—	—
	,,	,, ,,	−0·0001	+0·0001	—	—	+0·0003	−0·0005
	4196	5th ,,	—	—	—	—	+0·0005	+0·0006
	,,	,, ,,	−0·0001	+0·0001	—	—	—	—
	4197	9th ,,	−0·0001	+0·0002	—	—	+0·0020	−0·0010
	,,	,, ,,	−trace	+trace	—	—	—	—
No. II. Skin of amputated breast.	4197*a*	1½ hrs.	+0·0180	+0·0230	+0·0440	+0·0460	—	—
	,,	,,	—	—	—	—	—	—
	4198	3 ,,	—	—	+0·0040	+0·0080	+0·0300	+0·0200
	4199	5 ,,	—	—	—	—	+0·0120	+0·0092
	4200	5½ ,,	—	—	—	—	+0·0004	−0·0004
	4201	8 ,,	+0·0022	+0·0044	—	—	+0·0100	+0·0090
	,,	,,	—	—	—	—	—	—
	4203	21 ,,	+0·0050	+0·0175	+0·0100	+0·0250	—	—
	4204	22 ,,	—	—	+0·0126	—	—	—
	4205	23 ,,	+0·0040	+0·0060	—	—	—	—
	4206	3rd day	−0·0010	+0·0005	—	—	+0·0100	+0·0150
	4207	4th ,,	+0·0025	+0·0035	—	—	—	—
	,,	,,	−trace	+trace	—	—	—	—
	—	5th ,,	—	—	—	—	+0·0100	+0·0010
	4213	7th ,,	+0·0040	+0·0050	+0·0050	+0·0060	—	—
	—	8th ,,	−0·0005	+0·0002	—	—	+0·0013	−0·0011
No. III. Skin of abdomen.	—	6 hrs.	—	—	+0·0012	+0·0009	—	—
	4208–9	2nd day	+0·0040	+0·0080	—	—	—	—
	,,	,,	−trace	+trace	—	—	—	—
	4210	3rd day	+0·0011	+0·0021	+0·0007	+0·0040	—	—
	4212	4th ,,	+0·0023	+0·0058	—	—	—	—

mortem room, more or less doubtful results may be obtained, and unless due regard is paid to possible sources of fallacy, wrong conclusions may be drawn.

A principal source of fallacy lies in the electrodes; it is less liable to be of disturbing effect in the simple case of excitation by single shocks; it is more liable to give rise to ambiguous results in the more doubtful cases where alternating currents are required, the resulting polarisation in such case being less easy to recognise as such than in the case of single shocks. In such cases, when single shocks produce only polarisation effects, the voltage of any true response that may co-exist is low, and although alternating currents may then bring it into evidence, still we are not wholly free from a polarisation resultant which is of complicated origin and of inconstant direction.

Currents of a Berne Coil, supplied by 8 Leclanché Cells (11·5 volts).

alternating currents. 10000. {make + / break −}	alternating currents. 10000. {make + / break −}	Conductivity. (Not corrected for galvanometer and electrode resistance.)	Resistance.	
>+0·0100	>+0·0100	60	166667	Ingoing effects −0·0020 and −0·0015 with weak tetan.
+0·0350	+0·0180	75	133333	Another piece.
+0·0015	−0·0002	300	33333	Same piece, boiled.
+0·0500	+0·0200	30	333333	Another piece.
—	—	110	90909	Another piece.
—	—	210	47619	Another piece. Doubtful state.
+0·0006	−0·0006	210	47619	Same piece, boiled.
—	—	70	142857	Another piece.
—	—	200	50000	Ditto, boiled.
+0·0007	+0·0005	210	47619	Another piece. Doubtful.
—	—	210	47619	Ditto, boiled.
—	—	150	66667	Another piece. Doubtful.
+small	−small	250	40000	Ditto, boiled.
—	—	10	1000000	Good response. Cond. × 2 by tetanisation.
+0·0005	−0·0005	200	50000	Same piece, boiled. Cond. × 10 by boiling.
—	—	5	560000	Another piece. Galv. shunted 1/3. Cond. × 5.
—	—	25	112000	Same piece. Cond. × 7.
—	—	115	24348	Ditto, boiled. Cond. raised to 115, and not further altered by tetanisation.
—	—	40	250000	Another piece. Galv. unshunted.
+0·0002	−0·0003	200	50000	Ditto, boiled.
—	—	7	500000	Another piece. Galv. shunted 1/3. Cond. × 2·5 by tetan.
—	—	15	186667	Same piece. Series at +1000. Cond. × 35/15 by tetan.
—	—	35	80000	Ditto, ditto.
—	—	20	140000	Ditto, ditto, half dry.
+0·0550	+0·0160	7	500000	Another piece, half dry.
+small	−small	90	31111	Ditto, boiled.
+0·0060	+0·0020	15	186667	Another piece. Galv. 1/3. Cond. × 85/15 by tetan.
—	—	36	277778	Skin of nipple. Galv. unshunted. Cond. × 44/36. The surrounding skin is inactive.
—	—	180	55555	Ditto, boiled.
>+0·0100	>+0·0100	70	142857	Normal current = −0·0050.
—	—	60	166667	Another piece. E.M. discharge at −6°.
+small	−small	150	66667	Same piece at +14° after ½ hour at −6°.
—	—	80	125000	Another piece.
+0·0160	—	70	142857	Another piece.

Voltage of Response of Human Skin after Excitation by Induced

	Plate No.	Time.	Single break current.		Tetanisation for 5 seconds by			
			10000.		1000.		5000.	
			+ (outgoing).	− (ingoing).	{make − / break +}	{make + / break −}	{make − / break +}	{make + / break −}
No. IV. Skin of amputated leg.	—	3 hrs.	+0·0114	+0·0157	+0·0110	+0·0270	—	—
	—	4th day	+0·0063	+0·0043	—	—	+0·0166	+0·0166
	—	5th ,,	—	—	—	—	+0·0050	+0·0030
	—	6th ,,	+0·0001	+0·0004	+0·0002	+0·0012	+0·0064	+0·0042
	—	7th ,,	—	—	−0·0004	+0·0004	+0·0025	+0·0007
	—	8th ,,	−trace	+trace	{−0·0002 / +0·0002}	−0·0003	—	—
	—	9th ,,	−0·0002	+0·0005	+0·0016	+0·0016	+0·0058	+0·0006
	—	10th ,,	+0·0005	+0·0005	—	—	+0·0090	+0·0110
	—	11th ,,	+0·0005	+0·0002	+0·0004	+0·0002	+0·0040	+0·0016
No. V. Skin of thigh from the *post-mortem* room. Death by gastric carcinoma.	—	48 hrs.	—	—	—	—	—	—
	—	,,	—	—	—	—	—	—
No. VI. Skin of amputated breast.	—	2nd day	+0·0100	+0·0100	+0·0050	+0·0150	+0·0067	+0·0060
	—	3rd ,,	+0·0040	+0·0054	+0·0042	+0·0125	+0·0350	+0·0100
	—	4th ,,	−0·0006	+0·0001	−0·0002	+0·0002	+0·0003	+0·0010
	—	5th ,,	+0·0001	+0·0002	nil	nil	+0·0004	+0·0006
	—	6th ,,	+0·0060	+0·0060	nil	+0·0005	+0·0074	+0·0024
	—	,,	nil	+0·0002	—	—	—	—
	—	,,	nil	nil	—	—	—	—
	—	7th ,,	—	—	—	—	—	—
	—	,,	+0·0001	+0·0001	+0·0001	−trace	+0·0011	−0·0003
	—	,,	+0·0001	+0·0001	+0·0022	+0·0010	+0·0081	+0·0012
	—	,,	+0·0006	+0·0009	+0·0003	nil	+0·0017	nil
	—	,,	nil	nil	nil	nil	+0·0003	−0·0002
	—	8th ,,	nil	+trace	—	—	—	—
No. VII. Skin of amputated leg.	—	1st day	−0·0005	+0·0014	−0·0016	+0·0009	+0·0080	+0·0014
	—	,,	+0·0020	+0·0020	+0·0010	+0·0005	+0·0113	+0·0026
	—	2nd ,,	−0·0010	−0·0005	−0·0010	+0·0012	+0·0105	+0·0018
	—	3rd ,,	+0·0004	+0·0004	+0·0003	+0·0002	+0·0016	+0·0006
	—	4th ,,	−trace	+0·0006	+0·0012	−0·0005	+0·0050	−0·0025
	—	,,	−trace	+trace	—	—	—	—
	—	5th ,,	nil	+0·0003	{+0·0003 / −0·0006}	−0·0004	−0·0030	+0·0040
	—	,,	{−0·0002 / +0·0002}	+0·0010	+0·0025	−0·0025	+0·0075	−0·0033
	—	,,	−0·0001	+0·0002	+0·0008	+0·0005	+0·0026	−0·0003
	—	,,	—	—	—	—	—	—
	—	6th ,,	−0·0003	+0·0006	+0·0002	+0·0008	+0·0011	+0·0025
	—	,,	−trace	+trace	+0·0002	−0·0005	+0·0005	−0·0010
	—	,,	−0·0001	+trace	+0·0001	−0·0003	+0·0009	−0·0016
No. VIII. Skin from *post-mortem* room. Sudden death from heart disease.	—	3rd day	+0·0010	+0·0010	+0·0010	−0·0010	+0·0165	−0·0045
	4216	,,	+0·0010	+0·0010	+0·0010	+0·0010	+0·0080	+0·0005
	—	,,	+0·0005	+0·0005	—	—	—	−0·0012
	—	,,	−trace	+trace	—	—	—	—
	—	4th ,,	+0·0002	+0·0006	+0·0012	+0·0005	+0·0115	+0·0015

Currents of a Berne Coil, supplied by 8 Leclanché Cells (11·5 volts)—*continued.*

alternating currents. 10000. {make + / break −}	alternating currents. 10000. {make + / break −}	Conductivity. (Not corrected for galvanometer and electrode resistance.)	Resistance. (Not corrected for galvanometer and electrode resistance.)	
—	—	6, 10, 20	1666667 1000000 500000	Normal current = −0·0180. Conductivity increasing by single shocks and tetan.
—	—	40	250000	Normal current = +0·0100.
+0·0120	+0·0010	10, 40	1000000 250000	
+0·0087	+0·0018	200	50000	
+0·0075	+0·0012	50, 80	200000 125000	
+0·0100	−0·0080	20, 30	500000 333333	
+0·0025	−0·0005 +0·0005	75, 160	133333 62500	
+0·0050	+0·0090	28, 62	357143 161300	
+0·0035	+0·0030	125, 300	80000 33333	Fat removed. Normal current = +0·0060.
+0·0050	+0·0040	400	25000	
+0·0005	−0·0005	800	12500	Boiled.
+0·0072	+0·0060	28, 50	357143 200000	Normal current = −0·0140.
+0·0162	+0·0042	40	250000	
+0·0016	+0·0020	400	25000	Cancerous tissue gives no response.
+0·0008	+0·0012	500	20000	
+0·0250	+0·0150	15, 90	666667 111111	Good response.
+0·0030	−0·0001	300	33333	Same piece, boiled.
+0·0004	−0·0001	750	13333	Electrodes alone.
+0·0020	−0·0003	450	22222	New electrodes ; same piece of boiled skin.
+0·0025	+0·0002	300, 300	33333	Skin of nipple.
+0·0168	+0·0038	150	66667	Adjacent piece.
+0·0090	+0·0010	160	—	Ditto, fat removed.
+0·0005	−0·0004	550	—	Ditto, boiled.
+0·0020	−0·0010	125	80000	Skin dead ; putrefaction apparent.
—	—	90	111111	An injured piece of skin.
+0·0116	+0·0020	300	33333	Another and better piece.
+0·0100	+0·0025	50, 180	200000 55556	
+0·0032	+0·0073	150, 200	66667 50000	
+0·0100	−0·0060	100	100000	Another piece ; doubtful state.
+0·0017	−0·0024	400	25000	Ditto, boiled.
−0·0050	+0·0100	75, 100	133333 100000	Another piece ; anomalous response.
+0·0064	−0·0030	50, 75	200000 133333	Ditto, an hour later.
+0·0025	−0·0008	200	50000	Ditto, boiled.
+0·0004	−0·0008	400	25000	The electrodes alone.
+0·0010	−0·0002 +0·0005	100	100000	Same piece of skin replaced on same electrodes.
—	—	400	25000	The electrodes alone.
+0·0008	−0·0020	150	66667	Same piece of skin on fresh electrodes.
+0·0300	−0·0040	20, 50	500000 200000	
+0·0100	−0·0025	40, 80	250000	
—	−0·0010	80, 120	125000	
—	—	120	83000	After boiling.
+0·0100	+0·0040	40	250000	

Voltage of Response of Human Skin after Excitation by Induced

	Plate No.	Time.	Single break current.		Tetanisation for 5 seconds by			
			10000.		1000.		5000.	
			+ (outgoing).	− (ingoing).	{make − / break +}	{make + / break −}	{make − / break +}	{make + / break −}
No. IX. Skin from *post-mortem* room. Death by heart disease.	—	3rd day	+0·0002	+0·0003	+nil	nil	+0·0025	+0·0003
	—	4th ,,	nil	+0·0004	+trace	−trace	+0·0030	−0·0012
	—	5th ,,	+0·0040	+0·0080	nil	nil	+0·0090	−0·0005
	—	,, ,,	−0·0001	+0·0001	+0·0001	−0·0001	+0·0008	−0·0004
	—	6th ,,	−0·0003	+0·0003	+0·0008	—	+0·0070	−0·0020
	—	,, ,,	−0·0001	+0·0001	—	—	—	—
	—	12th ,,	−0·0002	+0·0006	—	—	—	—
No. X. Skin of amputated arm.	—	1st day	+0·0012	+0·0050	—	—	—	—
	—	6th ,,	−0·0008	+0·0016	—	—	—	—
			−trace	+0·0005	—	—	—	—
No. XI.	—	1st day	—	—	+0·0003	+0·0002	+0·0044	+0·0012
	—	2nd ,,	—	—	+0·0001	nil	+0·0030	−0·0020
	—	3rd ,,	—	—	+0·0017	+0·0067	−0·0050	{−0·0017 / +0·0013}
	—	4th ,,	−0·0010	−0·0007	−0·0045	−0·0018	−0·0110	−0·0087
	—	5th ,,	−0·0002	+0·0002	+0·0003	−0·0004	+0·0010	−0·0022
	—	6th ,,	+0·0003	−0·0002	+0·0002	−0·0005	+0·0014	−0·0015
No. XII. Great Ormond St. Foreskin, infant, of March 4th, 1902.	—	2nd day	+0·0050	+0·0025	+0·0250	+0·0200	—	—
	—	32 hrs.		—	+0·0110	+0·0100	+0·0159	+0·0133
	—	3rd day	+0·0006	+0·0022	+0·0020	+0·0011	+0·0076	+0·0031
	−0·0020	4th ,,	−0·0017	+0·0002	+0·0010	−0·0005	+0·0037	−0·0042
	−0·0006	5th ,,	−0·0002	+0·0002	+0·0004	−0·0004	+0·0022	−0·0022
No. XIII. March 4th was 1st day.	−0·0030	2nd day	+0·0010	+0·0014	+0·0015	+0·0012	+0·0045	+0·0036
	—	3rd ,,	+0	—	+0·0015	+0·0012	+0·0040	+0·0033
No. XIV. Guy's Hospital. Foreskin, child.	−0·0012	2nd day	+0·0003	nil	+0·0006	+0·0001	+0·0006	+0·0023
	−0·0034	3rd ,,	nil	+0·0007	+0·0013	−0·0007	+0·0117	+0·0008
	—	4th ,,	−0·0006	+0·0005	+0·0002	−0·0002	+0·0030	−0·0016
	−0·0002	5th ,,	−0·0004	+0·0003	+0·0001	−0·0001	+0·0020	−0·0017
	—	6th ,,	−0·0006	+0·0006	nil	nil	+0·0050	−0·0020
No. XV. Great Ormond St. Foreskin, of March 4.	−0·0013	3rd day	+0·0005	+0·0020	+0·0016	−0·0004	+0·0070	+0·0027
	—	4th ,,	+0·0009	+0·0011	+0·0004	−0·0001	+0·0030	−0·0007
	—	5th ,,	+0·0003	+0·0003	+0·0012	−0·0004	+0·0025	+0·0020
No. XVI. Ditto. ...	−0·0030	4th day	−0·0006	+0·0004	nil	nil	+0·0060	+0·0032
	−0·0010	5th ,,	−0·0002	+0·0007	,,	,,	+0·0016	{+0·0002 / −0·0002}
	—	6th ,,	−0·0030	+0·0030	,,	,,	+0·0028	−0·0032
No. XVII. Ditto. ...	−0·0030	6th day	+0·0002	+0·0005	—	—	—	−0·0033
No. XVIII. Great Ormond St. Foreskin of March 11th.	−0·0061	2nd day	+0·0007	+0·0021	+0·0008	+0·0005	+0·0034	+0·0015
	—	3rd ,,	+0·0008	+0·0037	+0·0026	+0·0007	+0·0073	+0·0023

Currents of a Berne Coil, supplied by 8 Leclanché Cells (11·5 volts)—*continued.*

alternating currents. 10000. {make − break +}	alternating currents. 10000. {make + break −}	Conductivity.	Resistance.	
+0·0050	+0·0005	130		
+0·0050	−0·0006	100	60000	After tet. 47000. R. measured.
+0·0300	−0·0035		1100000	Then 214000.
+0·0012	−0·0004			After boiling, only polarisation.
+0·0095	−0·0024			Another piece.
+0·0016	−0·0008			Ditto, boiled.
+0·0016	−0·0003	250, 250		R. unaltered by tet.
+0·0114	+0·0014	8, 14		In this observation the fallacy of the electrodes became obvious.
+0·0080	−0·0020	50, 90		
+>0·0100	+>0·0100	240		Skin boiled.
+>0·0100	+>0·0100	—		Electrodes alone.
+trace	−trace	—		Electrodes reamalgamated.
+trace	−trace	—		Skin replaced.
+0·0070	+0·0016		2000000	Reduced to 200000 W after tet.
+0·0060	+0·0030			
−0·0037	−0·0055			
−0·0060	−0·0133			
+0·0006	−0·0025			
+0·0017	−0·0029			
—	+0·0070	0·01=20		4 Lecl.
—	—	0·01=44		2 ,,
+0·0058	+0·0021	0·001= 5		,, ,,
+0·0060	−0·0050	0·001= 4		,, ,,
+0·0016	−0·0030	0·001=10		,, ,,
+0·0045	+0·0030	—	600000	Ohms.
+0·0038	+0·0025			
+0·0008	+0·0031	0·001=10	—	4 Lecl.
+0·0175	+0·0063	,, 6	—	2 ,,
+0·0036	−0·0042	,, 4	—	,, ,,
+0·0030	−0·0030	,, 7		
+0·0080	−0·0023	,, 3		
+0·0052	+0·0021	0·001=10		
+0·0062	+0·0008	0·001=11		
+0·0038	+0·0016	0·001=11		
+0·0120	+0·0044	0·001 5		
+0·0040	+0·0005	0·001 10		
+0·0071	−0·0017	0·01 6		
+0·0070	−0·0037	0·001= 4		
+0·0066	+0·0044	0·001= 9		
+0·0128	+0·0036	0·001=13		

General Remarks concerning the Preceding Table.

The table comprises groups of observations. Nos. I to XI were taken with skins sent to me by Mr. Plimmer from the operating theatre and the *post-mortem* room of St. Mary's Hospital. Nos. XII to XVIII were taken with, for the most part, an amputation skin sent to me from Guy's Hospital and from Great Ormond Street by the kind directions of Mr. Lane.

The data of both groups are in complete agreement with the statements made in the text, and with the representative experiment of which the graphic record is reproduced in fig. 1, viz., to both directions of single induction shocks, and to both pairs of directions of alternating tetanising currents the electrical response of living skin was outgoing (+).

A maximal value of the response under favourable conditions was + 0·04 to + 0·05 volt.

It was noticed on more than one occasion that the summated effect of tetanisation was of about equal voltage to the single response, to a single induction shock ten times as strong.

It was noticed more than once that the electrical response was small immediately after excision, greater 24 hours later, and subsequently diminishing day by day. I consider it probable that the smallness of the response of quite freshly excised skin is an effect of the excitation or "shock" of manipulation. In one particular instance, in which the skin had been very thoroughly cleared of subcutaneous tissue, I observed little or no response on the 1st day, and a typical response on the 2nd and succeeding days.

Skin No. 2 observation was most carefully followed out. It was undoubtedly living on the 7th day, when the following record was obtained, which illustrates

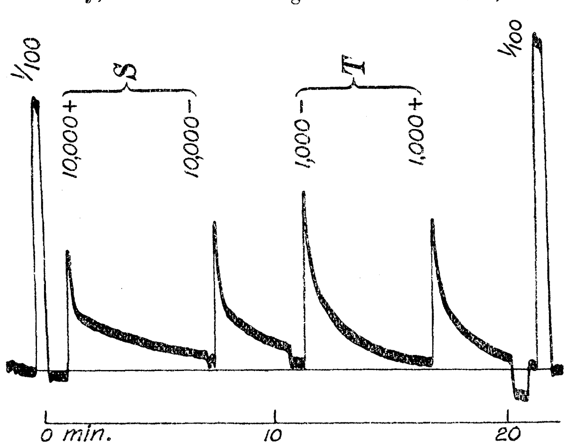


FIG. 5 (4213).—Skin No. 2. Close to nipple. 7th day after excision. Positive (outgoing) responses to + and − break induction currents (coil at 10,000), and to brief tetanisation in both pairs of directions (coil at 1000).

at the same time the fact mentioned above, viz., that the summated effects at a given strength of excitation are approximately equal to the single effects at ten times that strength.

The same skin afforded data that illustrate the progressively declining "vitality" of surviving skin. The following tabular summary of notes will suffice to illustrate this point:—

	Exc. by break 10,000 +.	Exc. by break 10,000 −.
1st day	+ 0·0180 volt	+ 0·0230 volt
2nd „	+ 0·0050 „	+ 0·0175 „
3rd „	—	—
4th „	+ 0·0020 „	+ 0·0030 „
5th „	—	—
6th „	—	—
7th „	+ 0·0040 „	+ 0·0047 „ (skin of nipple, fig. 5)
8th „	− 0·0005 „	+ 0·0005 „ (ordinary skin, polarisation only).

In all cases where note was taken of the "normal current" this was found to be of ingoing direction, *i.e.*, contrary to what might be given as current of injury from inner to outer surface. The voltage was in no case nearly as high as the voltage of a response—*e.g.*, the following are values taken almost at random from my laboratory note-book :—

Skin No.	I	1st day	−0·0027 volt.	
„	II	1st „	−0·0100 „	
„	„	2nd „	−0·0044 „	
„	„	3rd „	−0·0050 „	
„	„	4th „	−0·0040 „	
„	„	7th „	−0·0037 „	(nipple).
„	III	2nd „	−0·0040 „	
„	„	3rd „	−0·0060 „	
„	IV	1st „	−0·0130 „	

In the second group of cases, Nos. XII to XVIII, the skins were those of infants on whom circumcision had been performed, and included therefore a layer of mucous membrane. In these cases also the normal current as regards the layer of true skin was ingoing] and the response was outgoing. But the results are complicated by reason of the mucosa, which as far as I have yet seen responds usually by an ingoing current. Further observations directed to this point are, however, necessary.

The conductivity and its modifications are in all cases indicated by means of standard deflections by a given voltage—usually 0·01 volt. The resistance, in a few instances wheatstoned, is generally calculated by reference of the deflection to that of the same voltage through a megohm—and usually the disposition of the galvanometer was such that 0·01 volt through 1 meghom (*i.e.* $1 \cdot 10^{-8}$ amp.) gave a deflection of 10 mm. The values for conductivity are given in millimetres of deflection by 0·01 volt, and each millimetre expresses therefore $1 \cdot 10^{-9}$ mho.