Researches in relation to Cable Telephony

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Researches in Relation to Cable Telephony.

The subject which has engaged my attention and offered the best advantages for experimental work is cable telephony, that is, the transmission of speech underground or under sea. For this purpose I had the use of an artificial cable.

Telephony through cables is limited by two electrical properties — capacity and resistance. Their product limits the length of a cable through which it is possible to carry on conversation.

It was my purpose to determine, first, how much the artificial cable cut down conversation and, second, the effect of adding on a land line. Abundant experimental evidence was collected on the first part. But the determination of the second portion introduced such extraneous and unknown conditions that my results are not conclusive.

In the determinations of these products for the artificial cable I had the help of an assistant experienced in such work. In the communication with surrounding towns the great difficulty was to get a satisfactory comparative estimate of the speech.

The criterions for good business conversation is ^are^ that the speaker talk in ordinary tone and the listener hear without straining the attention. And the necessity for repetition should not be unduly frequent.

When using the magneto hand instrument as transmitter and having the cable in circuit the voice is much cut down in loudness. It was possible to carry on conversation to a higher limit in the laboratory than in practice for extraneous noises would drown the voice.

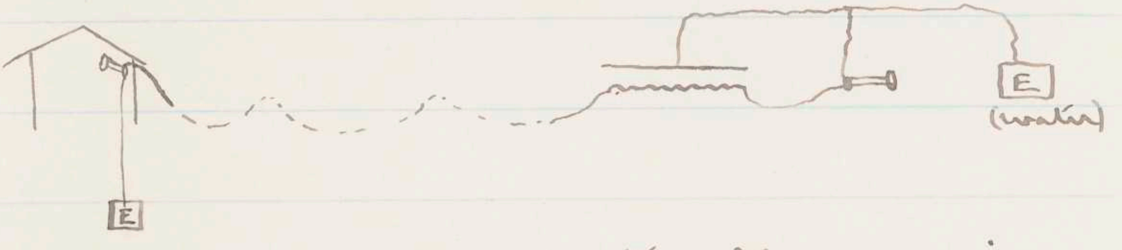
The limit for the Blake transmitter on single metallic circuit is 2500 to 3000 microfarad-ohms. and 12000 for complete metallic circuit. The limit for the Loud Speaker on single metallic circuit is 12000 to 15000 when three Lechanche cells are used in primary circuit. Of course these products are only approximations.

In anticipation of

taking underground cables for a subject of thesis I read all the literature accessible on that subject. Systematic and full notes were taken and I regret that time has not permitted me to incorporate in this thesis a history of these enterprises.

A study of the Quadrant Electrometer was made with a view of using it in cable testing and also to measure high resistance by fall of potential.

Experiments made on cable Telephony at 95 Milk St. Single metallic circuit to cupola.



My assistant was in cupola and we both had Blake transmitters and magneto receivers.

85-88 inclusive, C = 4.85 R=100 P=485.

Voice faint but distinct, rather faint for business conversation.

85-90 C = 7.27 P = 1100.

Quite faint, we repeat considerably.

85-93 C= 10.54 P= 2370

Can understand counting but for other conversation a good deal of repeating necessary.

85-93 & 99 & 114-118 C = 16.6 P = 6200

My assistant said: "could get sound and a couple of words" I could hear sound but it was quite out of question to understand.

The following set of experiments was conducted with the same circuit and instruments.

85-87 C = 3.85 P = 280

Speech faint but distinct.

85-88 C = 4.85 P = 485

Faint but distinct, rather low for business conversation. Quality does not seem much impaired.

85-89 C = 5.85 P = 730.

Same as above but have to listen more carefully.

85-90 C = 7.27 P = 1100

Much repeating.

85-91 C = 8.94 P = 1560

Understand still less.

85-92 C = 9.6 P = 1920

"Understands a few but not all words"

85-93 C = 10.54 P = 2370

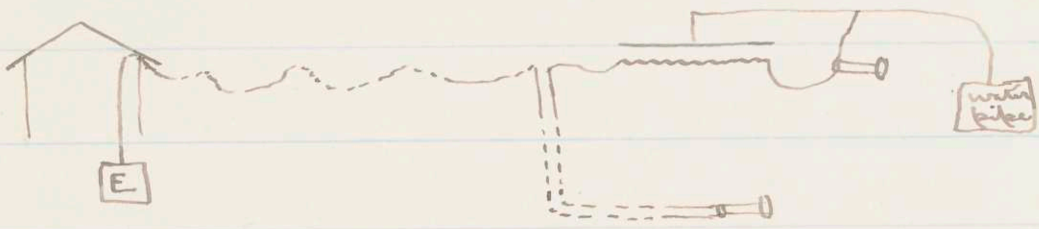
Could understand counting but not much else.

85-87	good but faint	a steady diminution in faintness.
85-86	less faint	
85	" "	

114-118 C = 5.02 P = 625.

Faint but by listening carefully can get most of reading.

The following set were made on single circuit with same connections as before except that my assistant was looped in between overhead and artificial cable on a circuit down stairs. This same circuit was used on all subsequent work involving use of single metallic circuit. In addition we had an independent circuit with morse instruments and a set of pre-arranged signals. This greatly facilitated the work.



In order to make evident without further search what instrument was used as transmitter when a certain result was obtained I have used the expressions M_1000, B_1000, L.S._1000, where

M stands for magneto hand instr.

B " " Blake transmitter

L.S. " " Loud Speaker.

and the figure following equals the product of resistance into capacity. Of course the Ball magneto-hand telephone was always used as receiver.

85 C = 1.15 M_30

Speech cut down in distinctness.

85-86 C = 2.25 M_125.

More cut down in quality than loudness.

85-88 C = 4.85 M_485

Understand conversation all right but quality impaired.

85-89 C = 5.85 M_730

Faint and considerable repeating necessary.

85-90 C = 7.27 M_1100

Very hard to understand at all.

85-91 C = 8.94 M_1560

Must shout to get intelligible words

85-92 C = 9.6 M_1920

I could get no answer. Now putting in Blake he hears all right

85-93 C = 10.54 B _ M _ 2370

He can barely hear sound through cable when I speak using a Blake but I can understand anticipated phrases and hear others but not understand them when my assistant speaks through his magneto. This seemed strange to me.

85-93 & 114-118 C = 15.5 B _ 5400.

Understands, but not distinctly. Gets reading on one repetition.

85-93 & 114-118 & 109-110 C = 18.16 B _ 7500.

Could hear nothing over cable with Blake. But could hear fairly well with a Loud Speaker (using only one La-Clanché cell in primary circuit)

The following set was carried on with previous circuit.

1-17-19-20 C = 4.45 M_445.

assistant can hear me distinctly. We are both using magneto instruments.

1-17-19-20-23-28-29 C = 7.25 M_1250

Can still hear well.

1-17-19-20-23-28-29-37-39 C = 9. M_2000

Conversation can still be carried on satisfactorily. This was subsequently verified by repetition and also the preceding one.

85-93 C = 10.54 M_2370

Can understand conversation. Fairly good for business.

85-93 & 114-115 C = 12.3 M_3380

Faint, could understand poorly.

85-93 & 114-116 C = 13.4 M_4000

I couldn't get communication with my assistant.

85-93 C = 10.54 M_2370

Not good enough for business

but could get individual words well.

85-93 & 114   C = 11.36   M-B-2840

I could get no reply from assistant when using the magneto. But switching in the Blake he "hears all right".

85-93 & 114-116   C = 13.4   B - 4000.

at first he didn't get me but later understands me. He says the sound is low and much muffled.

85-93 & 114-118   C = 15.56   B - 5400

much muffled, faint, and not good for ordinary conversation.

85-93 & 114-118 & 109-110   C = 18.16   B - 1500

Can't really hold conversation over line. He understands "listen on both circuits" and a few other frequently used expressions.

The following set was made with connections which have been previously described.

With no cable in we hear each other well.

85-87 C = 3.85 M_280

The conversation through magneto is not as loud as it was before but I don't miss any words.

85-89 C = 5.85 M_730

It is fainter but as regards distinctness would do all right for business.

85-90 C = 7.27 M_1100

This would hardly do for business conversation but we can understand.

85-91 C = 8.94 M_1560

By listening carefully can hear what I say but would be liable to loose parts of business conversation.

85-92 C = 9.6 M_1920.

must speak and listen carefully and with considerable repeating. Lose connection in reading but get many individual words.

85-93 C=10.54 M_2370

By speaking very loud understand anticipated phrases.

85-93 & 114-115 C = 12.3 M_ 3380.

Could scarcely get a thread of reading when shouted.

85-93 & 114-118 C =15.56 M - 5400

Could get none of the words in reading, trouble is not with faintness but too muffled.

85-93 & 114-118 & 109-110 C = 18.76 M_7500

Get familiar phrases as "Don't understand that", "Do you get this" but ordinary conversation can not

85-90 C = 7.27 B – 1100.

Loud enough but muffled.

85-93 C = 10.54 B – 2370.

About the same, could get reading all right – get every word.

85-93 & 114-118 C = 15.56 B – 5400

Couldn't get a newspaper sentence on three repetitions – very faint and muffled.

The following set was made using the Loud Speaker with three Leclanché cells in primary circuit. With no cable in, the sound was very loud and clear.

85-90 C = 7.27 L.S – 1100

The sound is not quite so loud but my assistant gets every word and says it is perfectly distinct. In these experiments on single circuit I did the talking and my assistant reported the quality. I could usually tell pretty well how he was hearing me by the frequency of repetition, &c.

85-93 C = 10.59 L.S. 2370

It is still very good business conversation, clear and distinct.

85-93 & 114-118 C = 15.56 L.S. 5400.

I read and he understands all. It lacks in loudness but is not muffled. When I shout close into mouth piece he hears me better. In ordinary tone can carry on conversation at distance of 3" to 6" from mouth-piece but in this latter case it would be a strain on listener.

85-93 & 114-118 & 109-110 C = 18.76 L.S. 7500

Just about the same only a little fainter than above.

85-93&114-118&109-110&1-17-19-20 C = 23.2 L.S. 11600

By raising voice can carry on business conversation. Speaking in an ordinary tone some repeating would be necessary.

85-93&114-118&109-110&1-17-19-20-23-28-29. C = 26 L.S. 15000

On reading in ordinary tone he lost quite a number of words but on speaking very loud he "hardly lost two words"

85-93&114-118&109-110&1-17-19-20-23-28-29-37-39

C = 27.8 L.S. 18700

Speaking in ordinary tone the conversation is not good enough for business but shouting he got all of reading. But he has to listen attentively in either case. This was with the use of three cells in primary circuit. Using two cells he hardly got a quarter of conversation when speaking in ordinary tone. When I shouted my assistant understood most of the words but it was not good enough for business. With one cell could not even get anticipated words. Finally I put the cable in shunt circuit and conversation was loud and not muffled.

Complete Metallic Circuit

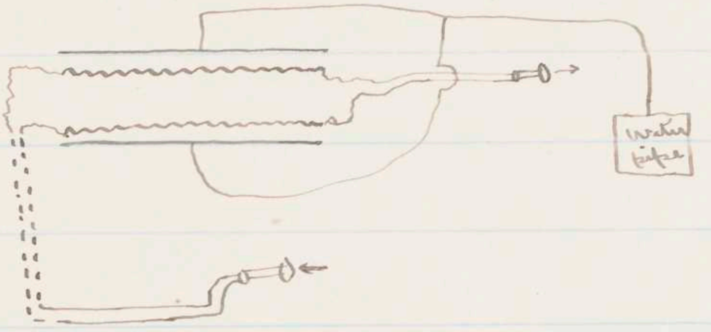
It is necessary to divide the product between the branches and I divided the condensers in this wise:

85 - 89	C = 5.85 R = 125	RC = 2800	(A)
1-17-19-20-23	C = 5.35 R = 125		
85 - 90	C = 7.27 R = 150	RC = 4700	(B)
1-17-19-20-23-28-29	C = 7.25 R = 175		
1-17-19-20-23-28-29-37-39	C = 9.05 R = 225	RC = 7650	(C)
92 & 109-110 & 114-118	C = 8.89 R = 200		

85-93 & 109-110 C = 13.74 R = 275
1-17-19-20-23-28-29-31-39 & 114-118 C = 14.07 R = 350
} RC = 17250 (D)

" " " " " " " " & 109-110 C = 12.07 R = 275
85-93 & 114-115 C = 12.29 R = 275
} RC = 13400 (E)

The circuit was connected in this manner.



My assistant had the transmitters down stairs and I listened on magneto.

With no cable in circuit the Blake is loud but perhaps a little bit hollow. The magneto is very clear and distinct, but not near so loud. The former instrument was well adjusted.

(A) Product = 2800

My assistant talks through the Blake transmitter and I can hear well. It is satisfactory for business conversation. The sound is slightly muffled and perceptibly cut down in loudness. With magneto the sound is not as loud but much clearer in articulation.

(B) Product - 4100.

He can hear me satisfactorily through magneto. The sound is not muffled but low. I can get him very well through Blake, understand all of conversation. His voice does not lack in loudness but it has a very peculiar cracking sound.

(C) Product - 7650

The difference between this and previous conversation is not very perceptible.

(D) Product - 17000

I only had magneto through

which to speak but could give my directions all right although the sound was very low.

With his Blake in circuit I lost considerable when he read in ordinary tone. When he shouted into transmitter it might be called acceptable business conversation. (for the listener)

With Loud Speaker (using two cells) I get everything nicely. It is very good business conversation.

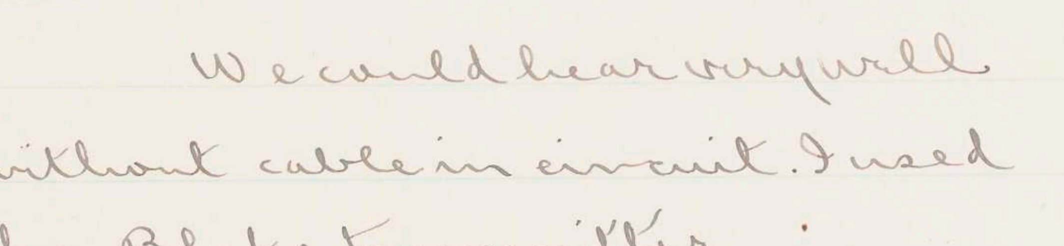
(E) Product 13400

He can hear my directions through the magneto but sound is low and he must listen attentively.

I could get his conversation through Loud Speaker when he no more than whispered.

Using the Blake and speaking in ordinary tone I called the conversation satisfactory for business.

The following set was made to determine what effect the leaky condensers had on speech. I selected fifteen with the lowest insulation resistance. It was a single metallic circuit with these connections.



We could hear very well without cable in circuit. I used the Blake transmitter.

94-98 inclusive

We hear without repetition but sound lacks volume and is "distant" He was speaking through magneto.

94-98&102-103-105-106-107

His voice was faint and far distant but distinct in articulation. Continuing conversation I could scarcely get such simple words as yes, no, &c. On taking the cable out of circuit my assistant says that he could hear my previous conversation with him but hardly thinks he could have understood reading.

94-98&102-103-105

This was better than the previous. I could get isolated words from him and he could understand my reading. It was "not A1 though", he said.

This set of experiments was made on the night of May 10th. The purpose was to study the effect on conversation of the insertion of both land lines and the artificial cable. By means of the overhead cable to cupalo I was connected with different lengths of land lines. The connection was always made through the cupalo to avoid passing through any "drops" in the Pearl St. Office. In all cases the persons with whom I talked used Blake transmitters.

I was connected over the Newburyport line and through the Central office with Mr. Jacques' house. The distance is 38 miles. I used a Loud Speaker.

We could talk quite well without cable in circuit.

85-93 C=10.54 Product_2370

"Fairly good business conversation."

85-93 &114-115 C=12.3 Product_3380.

"Did not get you very well", so he said.

85-90 C=7.27 Product_1100

Very good business conversation A I

85-93 C=10.54 _2370

"Fairly good, not quite good enough for business"

Conversation with the night operator at Newburyport was next tried. For some reason I could not hear him as well as I had heard Mr Jacques. I have these notes.

85-90 C=7.27 Product_1100.

Would do for business conversation fairly well _ loose a word occasionally.

85-92 C = 9.6 Product 1920.

Got the articulation of words satisfactorily. But loose occasional words in connected discourse.

85-93 & 114-115 C = 123 _3380

Could hear every word, but not very well.

Salem

The Newburyport operator connected me with Salem, twenty three miles distant. To my surprise the conversation with Salem was excellent, better than to Newburyport.

85-93 C = 10.54 Product 2370

Can converse without effort.

85-93 & 114-115 C = 123 _3380

Could hear Salem without repetition but Salem could not hear me.

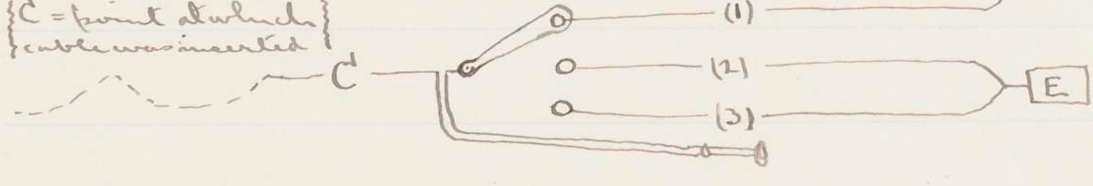
Haverhill

The operator connected

me with Haverhill which was 25 miles, so he said. This made a total length of land line of some 86 miles. The conversation with Haverhill was thoroughly unsatisfactory. I spoke very slow and repeated often. Considered it useless to attempt the insertion of any artificial cable.

The following results were obtained on the night of May 14th.

The connections were



arranged so that by shifting a three-point switch I could ground the line at will through (1), a magneto generator, (2) a Blake instrument or (3) the Loud Speaker.

This greatly facilitated communication for I could ring, or use either transmitter, without delay. A second switch permitted me to place either one Leclanché cell in circuit of Blake primary or three in primary of Loud Speaker.

Waltham

I was connected with the Waltham central office and have these notes.

We hear each other well with no cable in circuit. It is 8 or 10 miles to Waltham We are speaking through (1) overhead cable to cupola (2) an overhead cable to the Revere House (3) pole line to Charles River (4) submarine cable under the river (5) lastly, a pole line. There is a buzzing on the line. I ask him what it is. He says this line gets induction from the electric light wires in passing through Cambridge. He doesn't distinguish as well between the loudness of the Blake and Loud Speaker as I would suppose.

85-88 C = 4.85 Product 485.

He couldn't get conversation, only parts of it. Could scarcely make him understand a sentence. But I could hear him without any repetitions on his part.

85-90 C = 7.21 1100

He got such expressions as "Wait a moment", "Do you hear this" but failed to get connected discourse.

Salem

The direct line to Salem is tried with these results.

85-88 C = 4.85 485.

The operator understood me poorly. He says the sound is faint and no one but an operator would get the conversation.

85-90 C = 7.27 Product 1100.

The operator goes not get me at all when I speak through the Blake. We carry on conversation fairly well through the Loud Speaker. Then I shift to the Blake and he says that he hears me a little better!

Waltham

Returning to the direct line to Waltham these are the results.

85-88 C = 4.85 485.

The sound is faint, repetitions are necessary. It is hardly suitable for business conversation with the Blake. Business conversation can be carried on with Loud Speaker.

85-90 C = 7.27 1100

Can only get counting with the

Blake. Can talk passably well with the Lond Speaker.

Haverhill.

Lastly, I was connected with the through line to Haverhill. The distance is 32 miles. Without cable in circuit we could carry on conversation but it was some effort and there was a buzzing and roaring which was very disagreeable to my ear.

85-88 C = 4.85 _485

The effect of insertion of the cable was to make sound low and indistinct. It was Mr. Lewis with whom I was talking. In practice he had talked over worse lines but this conversation was exceedingly poor.

85-90 C = 7.21 _1100.

The sound grew fainter and

more distant and it was much strain to catch the words.

85-93 C=10.54 Product-2370.

This amount of cable was rather beyond the limit at which I could get the articulation of even single words.

Some inferences and conclusions regarding these land lines.

When I began conversation with the Salem operator and heard him better than the one in Newburyport I was much surprised. At first I ascribed it to earth currents and reasoned that there was a less difference of potential between Salem and Boston than Newburyport & Boston. Rain was falling at the time of the first experiments. If the line from Newburyport to Salem returns by the same poles that are used for the line between here and Newburyport two actions may have gone on. Leakage from one wire to the other may have occurred, or perhaps electro-dynamic induction. Either would account for the observed fact that conversation was better with Salem although the apparent length of the line was 38+23 = 61 miles.

Afterwards I learned from the Pearl St. night inspector that earth currents were very active that night and opened many of their "drops". They are troubled by earth currents more or less every night and particularly after a hot day. They have a regular course and successively affect lines converging out of Boston in this order. First, early in the evening, the Haverhill and Lowell lines, later the Worcester line, and finally late in the night, the influence shifts around to the Brockton and Providence lines. At the time I was speaking he mentioned the Worcester line as being badly affected at that time.

It is not known just what this influence is. "Earth current" is a term indiscriminately applied to explain any disturbance. A steady earth would not give rise to a sound in the telephone. But sound could be caused under this circumstance. If a heavy earth current traversed the line and there was microphonic action at some near high resistance leak undulations would be sent along the line as greater then less currents traversed it.

This plausible suggestion has been given to account for the noises heard nightly in the telephone. The moisture evaporated during the day on condensing at night may cause slight discharges upon the wire. It can be conceived how this effect minute yet rapid may cause a sound. another suggestion advanced is there may be thermo-electric effects in the earth plates.

I particularly noticed that I could hear these distant places better than they could hear me. The first cause for inquiry is in regard to the adjustment of my transmitters. I believe these instruments to have been in excellent condition, for without any cable in circuit they could hear me well.

The first night all the talking was done over the Newburyport trunk line. If there had been a high resistance leak near this end of the line the fact would be explained. The same action occurs in cable telegraphy when they can receive but not send at one end and vice versa at the other end. But using four different lines and always finding it the same I am compelled to give up that supposition.

One fact is apparent. The circuit was not symmetrical. Going one way it encountered the cable the first thing and the other way, the last thing.

I learn from Mr Schultz of the Signal Service that he observed some rather unusual variations in atmospheric potential on the night of May 10th. From 7 P.M. to 11 P.M. the readings changed from + 35.0 volts to − 42.6 volts. On May 14th at 7 P.M. the reading was − 59.1 and at 11 P.M. − 86.2

The Western Union people experienced some trouble the night of May 10th.

Artificial Cable

For the purpose of making telephonic experiments one half of an artificial cable was borrowed. Facts are not accessible concerning the time, place and method of manufacture and the material of which made. This might throw light on some of the phenomena observed during the following measurements.

The half borrowed is contained in two chests 4'8" long, 19½" broad and 3' high. Each chest contains forty condensers and an equal number of resistance coils of german silver wire silk wound. These coils are interposed between one set of terminals of the condensers and the other terminals of the condensers are connected to a common wire which may be grounded.

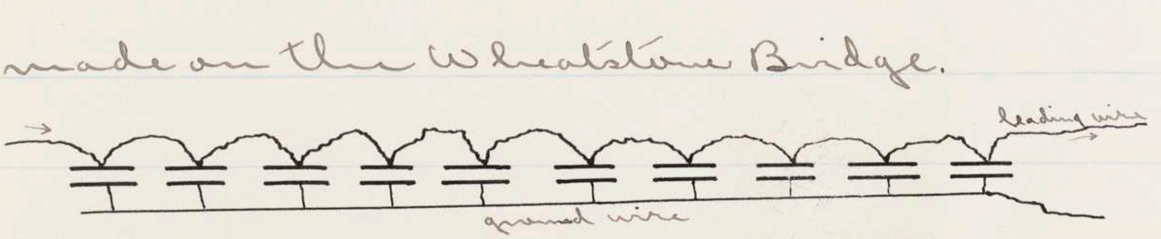
The difference between this and a natural cable is that in the latter resistance and capacity occur simultaneously along the line but in this artificial cable they occur alternately. The aim is however to obtain a similar effect by the frequency of the alternations.

This cable was made to duplicate an Atlantic cable and is said to be the equivalent of 2200 miles of such cable. It has been tested, at any rate, and on the head of the spool of each resistance coil is a number, evidently the resistance in ohms, and on each condenser is a label. On each label are three sets of figures. The first is the number of the condenser, the second looks a probable, but rather large, value for capacity the third is expressed as a product of two factors, the second being 10^6 which is the number of ohms in a mega-ohm. This is evidently the insulation resistance. Capacity and conductivity being the electrical properties of which I wished to make use I proceeded to make the appropriate measurements.

Measurements made on the Artificial Cable (at the M.I.T. Laboratory)

Line Resistance.

In order to compare with the given figures connections were made as here indicated and measurements made on the Wheatstone Bridge.

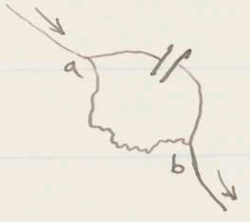


Resistance of leading wires = 2.072 It was impossible to get an exact balance on the Bridge which I attributed to some effect of capacity. The coils were measured in sets of ten and the results are here tabulated The first column gives the values as first measured, the second a set of values obtained the following day, the last column the sum of the numbers marked on the coils.

1-10	216.7			247.95
11-20	162.45	Leading wire = 1.96		246.58
21-30	235.75	corrected readings		246.54
31-40	208.0			248.22
81-90	247.4	247.4	245.44	245.52
91-100	246.9	246.9	244.94	244.80
101-110	232.2	246.8	244.86	246.61
111-120	213.1	248.2	246.24	246.58

1972.30

The same connections were made both days and I was surprised at the discrepancy. It was suggested that it might be due to absorptive effect as the condensers were virtually in shunt circuit with the resistances. If, in the adjoining



figure, the resistance ab was being measured and a condenser in shunt circuit kept absorbing electricity it would diminish the apparent resistance of ab. The battery circuit was kept closed long enough to get rid of any ordinary absorptive effect and moreover I believed the difference was of too great magnitude to be explained in this way.

The measured value of coils 81-100 inclusive = 422 ohms, the sum of marked values is 490.32. The measured value of whole number of coils = 1586. A measurement on another day gave a considerably different value = 1277.3 the mean of marked values is 1272.3

Detaching three of the coils I measured them separately and the results are recorded in the first column The slight

	measured	marked
9	24.13	24.13
85	24.27	24.25
101	24.99	24.92

differences between measured and marked values are easily accounted for by temperature-change in resistance.

My conclusion was that marked values on end of spools are correct for that for some reason it was unsafe to make the measurements with the condensers connected. I had assumed in commencing that the condensers had an insulation resistance of many mega-ohms but subsequent developments prove the difficulty to have been due to defective insulation.

Previous to locating the trouble I made some measurements on capacity with the following results.

Capacity.

Believing Thomson's method to be the equal of any in accuracy I made the connections as indicated on page 299 of "Kempe's Handbook of Electrical Testing"

Let C_2 = capacity of standard = 1 micro-farad.

R_1 = 1000 ohms and R_2 the adjustable resistance.

C_1 = the unknown capacity, then:

$$C_1 = \frac{R_2}{R_1} C_2 = \frac{C_2}{1000}$$

Using the subscript to denote the number of the condenser C_9 = 1.6 to 1.7

Although the resistance box permitted a closer adjustment of the ratio and the galvanometer was sufficiently sensitive yet I found it impossible to get a balance within close limits There was a wide range in apparent capacity due to differences in time of charging and mixing. I attributed it probably to residual charge. The time intervals I adopted were ten seconds for charging and the same for mixing.

In measuring C_{10} the spot moved to right (indicating too small a ratio) even when the ratio = $\frac{10000}{100}$

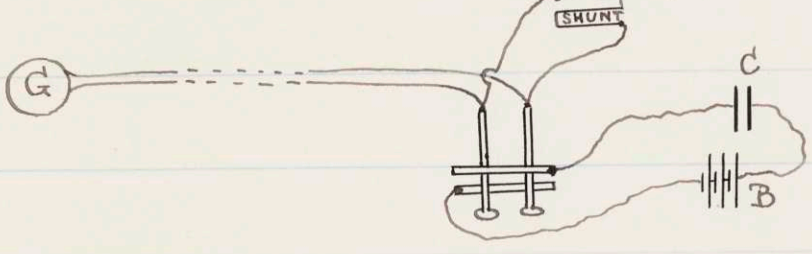
After working some time with C_8 and failing to get a probable value I placed its terminals in direct circuit with the galvanometer and the discharge of the absorbed charge caused a permanent deflection of 55 mm. In ten minutes it decreased to 36 and remained nearly the same during the next ten minutes.

The apparent capacity of C_7 was about 3.1 to 3.2 that is by adhering very closely to stated times of charging and mixing but it would be quite different with different time intervals.

Making $R_2 = 2500$ and $R_1 = 100$ and $E_2 = 0.5$ then $C = 12.5$ and I seemed to be nearer to getting no deflection with C_8 than before but I wouldn't be willing to give that figure as a value for its capacity. Now making connections for Scott's method (Kempe, p 302) the deflection indicated a ratio $= \frac{10000}{10}$ to be too small. I spent portions of several days in the use of these two methods but could not arrive at satisfactory results. From the anomalous results as given by these measurements of capacity I was convinced that the trouble might be due to faulty insulation.

Insulation Resistance

By the method used I had the condenser, battery, reversing key and Thomson galvanometer in direct circuit and the latter had a shunt which could be varied from ∞ to 0.



In the results which will be tabulated on the following pages I have used conventions as follows:

Let S = the value of shunt used

$M = \frac{G+S}{S}$ = it's multiplying power.

R = insulation resistance in megaohms unless stated to be in ohms.

C = the "constant" i.e. the resistance which if placed in circuit would give a deflection of one division.

t = time in minutes after completion of circuit before making reading or very often I have stated the limits in time between which two readings were made.

The zero is in the middle of the scale and division-numbers ascend each way. + indicates a deflection to the observer's right and – to the left. I have used "def" to denote a deflection as read and "d" to denote a corrected value i.e. one which is the mean of two readings or is corrected for displaced zero. But if some readings on opposite side of zero are not equal it does not follow that zero was displaced for on reversal the second and necessarily later reading may be less on account of decrease of absorptive effect.

No	S	M	def
C_{10}	S = 1	3901	off scale
C_9	5	781	155 to 185

I began with 24 cells of gravity battery but soon saw that I had more battery power than necessary and in the later work fewer cells were used.

I saw from the order of figure as would be given above that the difficulty in measuring capacity might be due to some peculiarity in the insulation. The Daniell's was the type of cell used

With 2 cells and $\frac{1}{10}$ mega-ohm in circuit $S = 10$ def $= -94$ & $+100$

$\therefore M = \frac{3910}{10}$, $d = 97$ $\therefore$ "C" $= 391 \times 97 \times \frac{1}{10} = 3793$.

No	S	M	def	d	Insulation Resistance
C_{10}	1	3901.	off scale =	250+	R < 3800 ohms.
C_9	2000	2.95	110 decr to 95		R = 12.
C_8	5	781.	110		R = 40 000 ohms.
C_7	1000	4.9	140+		R = 5 $\frac{1}{2}$
C_6	1	3901	off scale		R < 3800 ohms
C_5	500	8.8	120		R = 3.
C_4	1	3901	off scale		R < 3800 ohms
C_3	1		off scale		R < 3800 ohms.

C_2	1		Off scale		$R < 3800$ ohms.
C_1	5000	1.78	66		$R = 30.$
C_4					The insulation

resistance, as measured on Wheatstone Bridge = 522 ohms. A measurement made, I think, a day later did not give the same value. It was about 560 ohms but I noticed this phenomenon. I would apparently almost have a balance on the Bridge, when suddenly the spot of light would fly off the scale. This was repeated a number of times. This apparently variable resistance would not permit a zero adjustment of the balance.

In the preceding table the deflection with C_1 in circuit is stated to decrease. The current was stronger at first because a portion of the electricity was being absorbed. The reading decreased from 110 to 95 in five minutes. Now making circuit so as to allow the absorbed electricity to flow out through galvanometer the deflection is 110 and gradually decreasing is 90 seven (7) minutes later. In some condensers there appeared to be quite a marked absorptive effect, with others the deflection was quite steady.

Following are a few preliminary measurements on electro-static capacity.

Capacity

By Discharge-Deflection method. Using one cell for charging and $\frac{1}{10}$ shunt in discharging through galvanometer, the standard micro-farad gave deflection of 75 divisions. I adopted as standard intervals ten seconds for charging, then an equal period of rest before discharging.

C_7 deflections = 194

181

by charging longer = 218

From residual charge can afterwards get a discharge-deflection of 80

C_9 deflection = 128 $\therefore$ Cap = $\frac{128}{75}$ = 1.7

The effect of residual charge is very marked in giving several subsequent deflections (after allowing a short interval for accumulation of charge) and also a permanent deflection of some ten to twenty divisions on depression of galvanometer key. The results as given above for C_7 seem very irregular but subsequent results verified this irregularity.

Insulation Resistance.

With 1 Daniells cell and $\frac{1}{10}$ mega-ohm in circuit S = 30 def = −148 & +148

$$"C" = \frac{3930}{30} \times 148 \times \frac{1}{10} = 1938.8$$

No 81 At first while absorptive effect was going on most actively the deflection was off scale. At end of two min. def = 240; at end of six min def = 215

R = 2000 ohms (approx)

No 82 S = 1 def = 210 R = 2400 ohms

No 83 S = ∞ def = +13 & +4 ∴ d > 5 a reading the following day gave d = 5½ ∴ R = 400 approx.

With circuit as before the "constant" was determined for each day.

S = 40 def = +188 & −190 d = 189

$$"C" = 98.5 \times 189 \times \frac{1}{10} = 1861.7$$

No 84 S = 2000 def −70 & +50 d = 60 R = 11.

The spot of light returns to −6 as a zero on breaking circuit. The readings were taken in interval between third and fourth minutes after closing circuit and showed a disposition to decrease rapidly. In seven minutes it has decreased to +39

For my purpose any great precision in the measurement of insulation resistance was unnecessary as I only wished to know the order of figure. I don't believe that it is very constant with these condensers, at any rate, the absorptive effect has a very considerable influence. S=40 d=189 $98\frac{1}{2} \times 189 \times \frac{1}{10} = 1862$. = "C"

No	S	def	d	time	Insulation Resistance "C"=1862.
85	∞	+3 & −16	$9\frac{1}{2}$	5	R = 200.
81	1	214		3	R = 2200 ohms.
87	∞	+20 & −24	22	3-4	R = 85.
88	∞	+3 & −9	6	1-2	R = 320.
89	∞	+4 & −10	7	1-2	R = 280.
86	∞	+1 & −9	5	3-4	R = 370.
90	∞	+19 & −21	20	1-2	R = 93.

With three Daniell's cells and $\frac{1}{10}$ mega-ohm in circuit S = 10 def 110 & +210 "C" = 391 × 160 × $\frac{1}{10}$ = 6256.

No	S	def	d	time	Insulation Resistance.
91	2000	+172 & -182	177	2-4	R = 12
92	∞	+16 & -17	16½	2-2½	380
93	∞	+19 & -24	22½	1½-2½	280
94	1	off scale			R < 6000 ohms. (94–98)
95	1	.. ..			
96	1	.. ..	strongly		
97	1	.. ..			
98	1	.. ..			
99	∞	+116 & -124	120	1½-2½	R = 52.
100	1	+76 & -78	77	t < 3	R = 20000 ohms
101	1000	235			R = 6.
102	0	off scale			Probably a few hundred ohms.
103	1	70			R = 21000 ohms.
104	500	200			R = 3.6
105	0	off scale			Probably a few hundred ohms.
106	{ 0 / 1	65 / off scale			.. ..
107	0	off scale			.. ..
108	200	-102 & +145	123	2-3	R = 2½

109	2000	+172 & -114	143	t<3	R = 15.
110	1000	+180 & - 84	132		R = 9.7
111	0	off scale			Very low indeed
112	1	" "			" " "
113	20	+85 & -89	87	t<2	R = 0.37
114	∞	31 & -30	$30\frac{1}{2}$	t<2	R = 210.
115	∞	+76 & -84	80	t<$2\frac{1}{2}$	R = 78.
116	∞	+53 & -55	54		R = 116
117	∞	+194 & -200 -	197		R = 32
118	∞	+111 & -112	$111\frac{1}{2}$		R = 56
119	1	+190 & -190	190		R = 9000 ohms
120	0	+80			Very low

In the above table I have called "S = 0" when all the plugs of shunt were (firmly) in place and a deflection occurred. This indicated that a comparatively heavy current was flowing and the resistance of plug contacts was sufficient to divert a portion through the galvanometer.

Capacity

Discharge-Deflection method

The time intervals unless otherwise stated were ten seconds for charge ten seconds rest, then followed by discharge. The standard micro-farad with the charge of two Daniell's cells gave the deflections 145, 145, 145

No. 83	150, 152, 153, 153	$C = \frac{152}{145} = 1.05$
" 84	245, 235, 253 260+	$\frac{245}{145} = 1.7$
" 85	146, 144, 145	$\frac{145}{145} = 1.0$
" 86	156, 159, 155	$\frac{157}{145} = 1.08$
" "	120 giving 10 sec. charge and 60 sec. rest.	
" "	135 " " " " " 30 " "	
" "	163 " " " " " 3 " "	

" 83 Repeating observations with this condenser I find considerable variation in deflections due both to differences in time of charging and of rest.

With the standard condenser

I can detect no variation even by considerable differences in time of charging and of rest, in other words the absorptive effect is not perceptible and the insulation resistance is high.

It is to be noticed in these and subsequent figures that a large deflection which indicates a large capacity always occurs with those condensers of low insulation resistance. The readings are also less constant with these condensers. The insulation resistance of C_{89} which has just given quite inconstant readings is eleven mega-ohms.

With C_{86} I tried effect of giving different times of rest and the results are given on preceding page. The time of charging was the same.

I tried to measure the

capacity of condenser no 83 by Gott's method. At the expense of a good deal of labor I found that it was impossible to get the spot of light in equilibrium however carefully I might use the same time intervals.

By discharge-deflection C_{83} gives deflections 152, 155 152 and the standard micro-farad 195, 195

The following measurements were taken with estimated time-intervals of two seconds each for charge and rest. The standard micro-farad with one cell gives 72, 72

No		
85	83, 82, 81+	Capacity $= \frac{82}{72} = 114$
86	81, 78, 80	$\frac{80}{72} = 1.11$
87	114, 118, 120	$\frac{117}{72} = 1.62$
88	80, 80, 78	$\frac{80}{72} = 1.11$
89	84, 86, 72, 74, 75	= ?
90	100, 100, 99	$\frac{100}{72} = 1.4$

91 | 106, 118, 119, 118 $\frac{118}{72} = 1.64$

92 | 47, 48 $\frac{47+}{72} = 0.66$

| Standard (1 cell) again gives 72, 72

91 | 113, 114, 114 $\frac{114}{72} = 1.6$

92 | 47, 47, 48- $\frac{47+}{72} = 0.66$

93 | 64, 65 66 $\frac{65}{72} = 0.9$

96 | The insulation resistance is
between the limits 310 and 320
ohms as measured by Bridge.

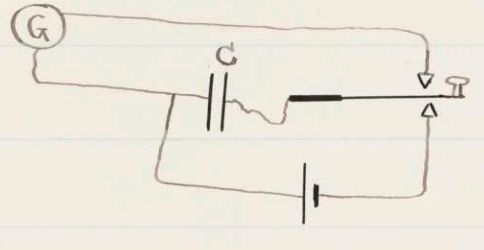
99 | 64, 63, 65 $\frac{64}{72} = 0.9$

101 | 212, 207, 216 $\frac{216}{72} = 3.0$

102 | 25 to 65 = differences in deflection
caused by small differences in
time interval. The insulation
resistance is very low

103 | 95 and less according to time.

The readings for values of capacity that I was getting were relative. They depended on time of charge and rest. By making the time intervals shorter I could get more constant results. I now changed the connections so that the condenser was respectively charged, then discharged as the key touched the lower then the upper contact. By touching down then immediately allowing to return I got an



almost instantaneous charge and discharge. The connection had the further advantage that the condenser was always discharging itself between times. The following measurements were so made:

Nº		Capacity
99	76, 76	$\frac{76}{72} = 1.06$
101	231 228	$\frac{228}{72} = 3.2$
104	175 to 185, 187	$\frac{180}{72} = 2.5$
108	200, 191, 186, 175,	$\frac{192}{72} = 2.7$
"	226, with 45 sec charge and immediate discharge.	

109	125, 123, 123	$\frac{123}{72} = 1.7$
110	105 110, 110	$\frac{110}{72} = 1.5$
111	deflection off scale. If I got an abnormally large deflection, then looked up the insulation resistance of that condenser would always find it low.	
114	58, 59, 59	$\frac{59}{72} = 0.82$
115	67, 68, 67+	$\frac{67}{72} = 0.93$
116	80, 80, 81	$\frac{80}{72} = 1.11$
117	87, 87, 87.	$\frac{87}{72} = 1.2$
118	69, 69, 69	$\frac{69}{72} = 0.96$
—	Standard micro-farad gives 72, 72.	
99	67, 67. 67	$\frac{67}{72} = 0.93$
93	67 67 68	$\frac{67+}{72} = 0.93$
92	48 48	$\frac{48}{72} = 0.67$
91	118, 122. 120	$\frac{120}{72} = 1.67$
90	102, 102	$\frac{102}{72} = 1.42$
89	67, 72, 67, 75	= ?
89	taken 3 hours later, 72, 73, 74	$\frac{73}{72} = 1.0$

88	72, 70, 72	$\frac{72}{72}$ = 1.0
87	114, 116, 117	$\frac{116}{72}$ = 1.6
86	75, 80, 80, 79.	$\frac{79}{72}$ = 1.1
85	83, 83, 83	$\frac{83}{72}$ = 1.15
84	220, 226 227 222	$\frac{226}{72}$ = 3.0
83	80, 80, 79, 79	$\frac{80}{72}$ = 1.1
101	205, 219, 215.	$\frac{219}{72}$ = 3.0–

At this point in the work I put up a telephone circuit and tried the effect of the cable on telephonic transmission. I used a Blake transmitter and magneto receiver and a complete metallic circuit. I used nineteen of the best condensers and the product RC was equally divided between the branches. Conversation was considerably muffled but not prevented. The total capacity = 25 + and total resistance = 470 and product = 12000 micro-farad-ohms.

I next proceeded to measure the insulation resistance and capacity of each condenser in the second chest. The readings of deflections in insulation resistance were taken as soon as the spot came to rest. In measurements of capacity I took an instantaneous charge and discharge

Insulation Resistance

constant _ $S = 40$ def $= +138$ & -143 $R = \frac{1}{10}$

$$\text{"C"} = \frac{3940}{40} \times 140 \times \frac{1}{10} = 1380$$

No	S	def	Insulation Resistance
1	∞	+48 & -53	R = 27.3
2	0.1	70	R = 500 ohms.
3	1.	94	R = 3100 ohms
4	0.1	86	R = 400 ohms.
5	1000	113	R = 2.5
6	0.2	48	R = 1400 ohms.
7	1000.	78	R = 4.
8	10.	129, declines to 120 and on.	R = 30,000
9	1000	72	R = 4.

10	0.3	80	R = 1380 ohms
11	0.1	180 to 190	R = 200 "
12	0.1	90	R = 400 "
13	0.1	135	R = 300 "
14	0.3	62	R = 1700 "
15	0.3	40	R = 1200 "

Constant S = 40 defl +142 & -141 R = $\frac{1}{10}$

$\frac{3940}{40} \times 141\frac{1}{2} \times \frac{1}{10} = 1390.$

16	300	73	R = 1.4
17	∞	20	R = 70.
18	3	85	R = 12000 ohms.
19	∞	14	R = 100.
20	∞	37	R = 38.
21	10	66	R = 50000 ohms.
23	0.1	200+	R = 180 ohms.
23	∞	4.	R = 350
24	1	55	R = 1000 ohms.
25	30	78	R = 130000 "
26	0.3	113	R = 1000 "
27	0.3	55	R = 2000

28	∞	17	R = 80
29	∞	9	R = 150
30	0.1	180	R = 200. ohms
31	100	49	R = 700000. "
32	0.1	190	R = 200 "
33	300	103	R = 1.
34	0.1	off scale	R < 100 ohms.
35	1.	86	R = 4000 "
36	0.3	84	R = 1400 "
37	∞	7	R = 200.
38	0.1	off scale	R < 100. ohms
39	∞	35	R = 40.
40	10	83	R = 40000 ohms.

Capacity

Discharge - Deflection method.

Standard 72, 72

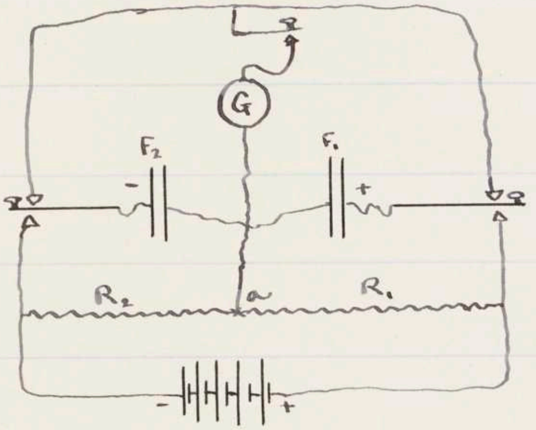
1	101, 97, 97, 97	$\frac{97}{72} = 1.35$
5	198, 198	$\frac{198}{72} = 2.75$
5	225, with 5 sec charge, instantaneous discharge.	

5	180, with 5 sec charge, 5 sec. leakage.	
7	192, 192	$\frac{192}{72} = 2.7$
9	109, 109, 105, 109	$\frac{109}{72} = 1.5$
16	233, 233	$\frac{233}{72} = 3.2$
17	93, 95, 95	$\frac{95}{72} = 1.3$
19	58, 62, 60, 60	$\frac{60}{72} = 0.83$
20	67, 67, 67-, 66	$\frac{67}{72} = 0.97$
23	64 63 63+	$\frac{63}{72} = 0.9$
28	84+, 85, 84+	$\frac{84}{72} = 1.2$
29	50, 50+, 50+	$\frac{50}{72} = 0.7$
33	270+, 270+	$\frac{270+}{72} = 4.$ (approx)
37	54, 56, 57,	$\frac{56}{72} = 0.8$
39	77, 75, 75	$\frac{75}{72} = 1.0$

A list of those condensers which I considered most suitable for telephonic work is given on this page. The two columns give respectively the insulation resistance in mega-ohms and the capacity in micro-farads.

1	27.3	1.35	88	320	1.0
17	70.	1.3	89	280	1.0
19	100.	0.83	90	93	1.42
20	38.	0.97	91	12	1.67
23	350.	0.9	92	380	0.67
28	80	1.2	93	280	0.93
29	150.	0.7	99	52	0.93
37	200.	0.8	109	15	1.7
39	40.	1.0	110	9.7	1.5
83	400.	1.1	114	210.	0.82
84	11.	3.0	115	78.	0.93
85	200.	1.15	116	116	1.11
86	370	1.1	117	32.	1.2
87.	85	1.6	118	56.	0.96

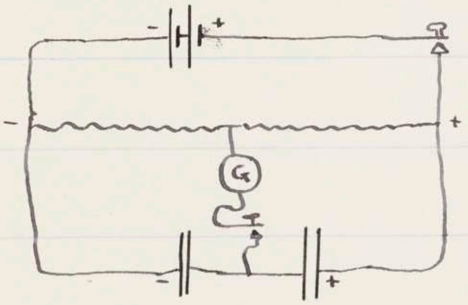
The effects of Leakage and absorption on the apparent capacity of condensers when measured by Thomson's and Scott's methods.



Annexed is a diagram of connections for the former method. The equation is $F_2 = \frac{R_1}{R_2} F_1$

If F_2 leaks the potential at a is lowered. The condenser F_1 then has a larger charge and F_2 a smaller one. On discharging F_1 predominates and the next adjustment would be to make the ratio smaller.

The effect of a continued discharge of absorbed charge in F_2 which occurs on mixing is to require a less value of R_2 in order that the quantity discharged by it may neutralize that from F_1. Its capacity then as measured by the ratio $\frac{R_1}{R_2}$ is too large. This is what I observed. The absorptive effect predominated.



These are the connections for Gott's Method. The equation is $F_2 = \frac{R_1}{R_2} F_1$

Suppose both condensers perfect and R_1 adjusted too small then the discharge will be downward through galvanometer and the next step is to make the ratio larger. Now if the discharge is downward one continually adjusts the ratio larger and this is what happens with a leaky condenser. For if both keys are depressed we may look upon the condenser F_2 as in shunt with R_2 and the current would flow downward.

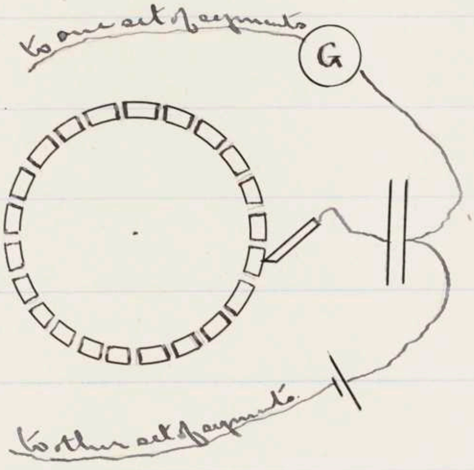
A continued absorptive

effect would also be indicated on the galvanometer in the same way.

It is common so far as I have been able to learn to use the discharge deflection method in the measurement of capacity of land lines. Thomson's and Gott's are null and therefore more accurate methods and the reason for the practice may not be evident at first sight. The foregoing considerations of the effect of leakage show why it is not desirable. A practical difficulty is that the value is reached by approximations towards the final ratio and the adjustment may be very troublesome. On the other hand the discharge deflection method furnishes a result at every discharge.

If time had permitted I should like to have seen what the apparent capacity of these condensers was by a method of rapid charge and discharge. This would not be equivalent to the discharge-deflection method for the needle would be acted on, not by a single impulse, but by rapidly recurring ones. If the recurrences were rapid enough the galvanometer needle would be steadily deflected. The apparatus would be quite simple.

Alternate segments in the perimeter of a rotating wheel with connections in this wise might give the charge and discharge. Have one of the sets of segments constantly in connection with battery, the other set, to galvanometer.



Have the other terminals of both connected to same terminal of condenser and the other terminal of condenser to a brush rubbing against perimeter of wheel. The rotation of wheel would effect the desired object. The condenser would be alternately charged and discharged and by varying the velocity of rotation of the wheel this could be made to occur any desired number of times per second.

Let C = the capacity of the condenser, V = the difference of potential established between its terminals, and n = the number of discharges per second. Then

$n C V = Q$ is the quantity flowing through galvanometer. This instrument may be calibrated to find the quantity per second corresponding to a given deflection. Knowing n and V, $C = \frac{Q}{nV}$ may be calculated.

Or, a second method of calibration would be to have C a known quantity, that is, use a standard condenser, and, taking n and V with known values, a constant would be obtained. Other condensers giving other deflections would have capacities equal to the ratio with the constant.

It would be very interesting to get a series of results with different values of n and V and see how the the values of capacity agreed.

This method would further afford a means of studying the effect of continual charging. During my work I rather got the idea that the absorptive effect of the first charge was so strong as to influence measurements made immediately or soon afterward.

If the values of capacity thus obtained were used in telephonic experiments it might be desirable to use that value of capacity correspond-ing to n = the average number of impulses through the telephone. Such results would be interesting in making a thorough investiga-tion of the subject. But my purpose was to find if this cable cut down speech to the same extent as a real cable and values of capacity thus obtained would not be comparable with those as ordinarily obtained.

The Quadrant Electrometer.

The electroscope was the earliest instrument used to indicate the presence of electricity. From it grew the electrometer an instrument to measure the intensity of the electric force.

The forms first used were Repulsion Electrometers. They did not fill the requirements of a highly accurate scientific instrument. Among other things, they did not permit easy adjustment to different grades of sensitiveness.

The first quadrant electrometer was made and used in 1861 and attracted disc electrometers have been brought out within a few years. Of the latter I know little. Only a few have been brought to this country and I have no knowledge of their extended use.

The second mentioned class is the best known. The quadrant electrometer consists essentially of four "pill-box" quadrants within which is suspended a vane which is hung symmetrically between them. Alternate quadrants are connected & they and the vane are charged. The latter is acted on by an electrical couple which turns it in proportion to the difference of potential established between the quadrants.

The principle on which the instrument is founded is beautifully simple. Use is made of devices which render it exquisitely sensitive and yet it has a wide range of adjustment.

The instrument is only suitable for stationary work. An advantage is the simplicity of construction. Its advantage over the galvanometer consists in not being affected by magnets or moving machinery. It does not like the potentiometer require the passage, and, hence, the use of a current.

Uses of the Instrument.

It may be used to measure:

(a) Insulation Resistance – The measurement is made by fall of potential and the equation is $R = \frac{t}{S \log_e \frac{P}{p}}$

where t = time in seconds

S = capacity in microfarads

$\frac{P}{p}$ = ratio of deflections.

The method makes possible the measurement of higher resistances and furthermore furnishes a continuous test which is an important consideration in cable testing.

(b) Resistance of Conductor - The current may be measured in any part of circuit by galvanometer or other means. Then measure by electrometer the potential-difference between terminals of conductor and by Ohm's law $R = \frac{E}{C}$

Or, a simpler method and one not involving the use of the galvanometer is this. Place a known resistance in circuit with the unknown. Then measure the potential-difference between terminals of each. These resistances will be directly proportional to the deflections.

The quadrant electrometer may also be used to measure internal resistance of battery, capacity, atmospheric electricity, and other uses are readily suggested. I believe that it is not commonly used for commercial purposes except in cable testing.

If the proper co-efficient is known the results may always be changed to absolute units.

During the time of my work on the instrument I met with certain difficulties the cause of which is obscure. The results of my observations are given in the following pages.

Experimental Work on Quadrant Electrometers.

The Clifton Instrument.

The instrument was taken apart, carefully cleaned and the vane mounted by a bi-filar suspension, using a moderately light silk fibre. Reading are made by a lamp and scale placed 3' 4" from instrument.

I give in the few following pages my notes made during the observations and occasional comments made there-on. In some cases the reasons for certain actions are evident; in others, not. The quotation marks used refer to my note book.

"Placing four quadrants to earth and charging vane by electrophorous, I can, by moving radially the adjustable quadrant, make deflection to either side." By this adjustment I hoped to get the quadrants and vane in a position of symmetry.

I brought three well-insulated leading wires - one from vane and two from quadrants - to table in front so that I could charge vane and quadrants and watch scale simultaneously.

"I notice this peculiarity suppose adjustable quadrant out of adjustment so that on charging needle there is a convenient deflection and leading wire from vane comes to table and on the table sets the electrophorous. On touching the top of electrophorous with the finger the deflection decreases, but on approaching disc to terminus of wire, the vane is violently deflected."

For conciseness I have

used abbreviations for some words which are very frequently used

Q = quadrant or quadrants

N = vane, or needle as I often call it.

E = electrophorous.

B = battery.

"Charging N by E can get deflection from one end of scale to the other by reversing the poles of 50 cells water B between Q"

"0 is shifting"

To study the effect of adding cells between terminals of Q in order to see if the differences were constant I charged N by E and successively added 5, 10, &c cells between leading wires of Q

"The readings could not be made exactly as the deflections were always increasing with the time"

No cells water B	Readings	Differences	No cells water B	Readings	Differences
0	−20		0	+10	
+5	+14	34	−5	−42	52
+10	+52	38	−10	−72	30
+15	+95	43	−15	−102	30
+20	+140	45	−20	−150	48
+25	+185	45	−25	−190	40
+30	+227	42	−30	−230	40
+35	+260	33	−35	−280	50

This table made evident the impossibility of exact scientific measurements when deflections did not assume a constant value but kept slowly increasing. Many subsequent measurements were made to test the extent of this effect.

"Place −20 cells water B to quadrants and get a deflection of −174 [not same as in preceding table] now instead of diminishing from loss of charge in N (as would be supposed) in several minutes it has increased to -183. On jarring table on which stands the water battery, the spot moves uneasily usually increasing slightly. It is apparently stationary at -183."

"Returning 50 minutes later the reading is 187½ all this time the vane and its Leyden jar were insulated by the withdrawal of charging wire. On lowering charging wire into acid the deflection regularly decreases." In this last case the decrease was evidently due to greater opportunity for escape of needle-charge.

"The electrophorus rests on table. On touching its top plate with finger tip the deflection rapidly decreases but on raising disc the spot instantly leaves scale."

"Dry pile has been connected to needle for 5 hours. Zero is at -7."
To make sure that the needle was fully charged I adopted this precaution but it did not prevent the deflections from increasing.

No. cells water B	Readings	Differences
0	-7	
-5	-40	33
-10	-70	30
-15	-107	37
-20	-155	48
-25	-220*	65
-30	-250	30

* an interval between this and the previous reading during which other deflections were taken.

The readings in in this and also in the previous table were taken consecutively with this single exception.

Another point that had before been apparent was also emphasized. It didn't do to handle the connecting wires with the hands and in later work I avoided that as far as possible.

In the following readings the zero was evidently considerably displaced. Twenty four gravity cells gave a reading − 65 (increasing) "Reversing poles the reading is 0 and soon increases to + 9. Why always the increase of deflection after swinging has stopped? Can it be a yielding of fibre. Last given value has now increased [while writing] to + 14. Dry Pile has been connected to needle some 24 hours."

With dry pile to needle and 45 cells B to Q I find deflection increases in 5 min. from 14 to 26 and in 5 min. more to 32.

To observe if the zero was

constant I deflected in one direction and it came back to - 38. Deflecting in the other direction it comes back to - 42. This showed an undesirable inconstancy in the zero.

"Dry pile has been dis-connected two hours and zero is at +7.3. Dry pile to needle over night and at 11 a.m. zero is at 21. This indicated that zero was not the same for charged and uncharged needle, in other words, a lack of symmetry. Twenty cells water B to A give a deflection +43 which increases to +46 in three minutes. Comes back to +23 as zero. With 50 cells water B the deflection is +102 and increases to 113 in three minutes. Manipulating the key to allow the spot to come back without oscillations the zero is at +36 and in three minutes has decreased to +30½

Reversing the poles of 50 cells water B the deflection is −43; in three minutes increases to −60; in six min., to −64; in fourteen, to −70 This was at 11:30 a.m. at 1:20 P.M. the reading is −94 and at 2:10 is −101 allowing to return without oscillations the zero is at −18.

at 2:30 P.M. zero is at −4.5

" 2:53 " " " " −2.8

" 5:05 " _ charge needle by electrophorous. Ten cells water B to Q give a deflection −94 and while writing it increases to −104. next morning the reading is −123. Reversing the poles of battery at 8:55 a.m. the spot of light moves to −34; at 10:05, is at −9.

The electrometer can not be scientifically useful for quantitative work while there are such uncertain indications of the true value of a deflection.

The suspending fibre was of moderate weight and it was suggested that the trouble might be due to torsion. In a bi-filar suspension the deflecting force is balanced by a raising of the needle and torsion is not supposed to play any part. To test the effect of a lighter suspension, after several trials I got in a very fine silk fibre and continued to make observations similar to the previous ones.

With dry pile to vane zero is at +5½

5:31 P.M. — 10 cells water B give deflection —78.

in 5 min. has increased to —82.

at 9 a.m. next morning the reading is - 163
Reversing the poles it is + 138
at 10.45 a.m. has increased to + 147.

In order to show the extent of the resistances which diminish the oscillations I took the following readings as the vane swung to and fro.

260 - 47 - 16 - 2

255 - 47 - 14 - 1½

I made a good many more observations with the Clifton instrument and met with results sometimes uncertain, often unexplainable.

As an indication of the delicacy of the instrument I will mention an incident. When I charged the needle with electrophorous I would discharge by touching terminal with finger tip.

This was always satisfactory except one wet morning on commencing work I couldn't discharge the needle in the usual way. Soon after I took off my rubbers and the difficulty disappeared. I believe the trouble to have been due to their insulation.

Mascart Instrument.

The sensitiveness of this instrument may be varied by a convenient arrangement for altering the distance apart of the fibres of the bi-filar suspension.

With dry pile to vane and fibres widely separated 5 cells water B gave a deflections of 50 divisions; 15 cells, about 150 and 25 cells, 280. Then to see how well the charge was retained I raised the upper screw contacts of reversing key. It soon sank to 246; in 15 min. to 194; in 45 min. to 130. This showed the effect of combined leakage of electrometer leading wires and reversing key.

Twenty five cells water B to a gave a deflection of 245; in 3 hours 10 min. it increased to 270

The dry pile which I have previously spoken of using is Zamboni's type. It is made of discs of paper silvered on one side and coated with bin-oxide of manganese on the other. Many of these discs are pressed together and are protected by an exterior coating of sulphur. Ganot makes this statement: "A Zamboni's pile of 2000 couples gives neither shock nor spark but can charge a Leyden jar or other condensers. A certain time is, however, necessary for electricity only moves slowly in the interior." I left the dry pile in connection with the needle over night or even longer in certain experiments but that did not seem to avoid the difficulty of increasing deflections.

In later work I had the use of several more dry piles of a different type and for distinction marked them "A", "B", "C", &c. They are really dry Daniell's cells and, like other dry piles, depend on the hygroscopic action. By placing two of them in series I could get both spark and shock.

On commenced work one morning I noticed the zero of Mascart was at + 1.3. With 45 cells water B to vane and dry pile "A" to Q. I didn't observe a tendency of deflection to increase. The readings obtained, direct and reversed, were +211 & -204 allowing needle to return without damping the spot stops at +7.4

With same charge in needle and dry pile "B" to quadrants the deflections were +210 and -202. Spot comes back to +7.5 as zero.

Without touching connections through reversing key to quadrants I detach water battery and ground needle. On charging quadrants as before by dry pile "B" the deflections are +240 & -230 or more than before. I didn't expect that there would be any deflection.

With Zamboni dry pile to N and "B" to quadrants the reading is -260 and gradually increases to -290. Then with 50 cells water B to quadrants the reading is 289 and increases in 5 min to 294 and in half hour to 327.

Charging vane by spark and quadrants by Daniell's cell the deflection are +58 & -23. But charging vane by electrophorous had first shifted the spot some twenty divisions to right.

With dry pile "B" to vane and Daniells cell to quadrants the readings are +54 & -30. The zero is at +13. Therefore the deflections are +41 & -43. +13 also seems to be the zero with needle to earth.

Sometimes, I observed, the deflection did not increase. I was about to make a study of the conditions under which this occurred when the artificial cable arrived and my attention was otherwise claimed.