# *Colorado Springs Notes*

Nov. 1—30, 1899

Want of time compelled omission of following items partly worked out:

Nov. 27, 28 Corrected and completed results of experiments of

Nov. 3 $\left\{\begin{array}{l}\text{with wire of different}\\ \text{lengths and ball}\end{array}\right\}$, 19 and 21

Nov. 29, 30 a) Extra coils in series exciting one another,
b) Methods of tuning by telephone,
c) Exciting receiving circuit through small sensitive arc
$\Big\}$ complete description

Patent matter worked on Nov. 1—30:

Exclusion of messages in telegraphy:

a) Two or more synchronized receiving circuits controlling receiver
b) Key or safety combination
$\Big\}$ text to be completed.

Colorado Springs Nov. 1, 1899



Measurement of inductance of new extra coil built chiefly for investigating propagation of waves through the ground and similar objects also to investigate further the behaviour of strong streamers.

The frame was made of light notched woodwork fastened to three strong wooden rings. Provision was made for 106 turns. The rings were 8 feet in diam. outside taking further 1½" on each side for the crosspieces the total diameter of coil inside was 8'3". The length was 8 feet less 1½" on top and ½" on bottom making total length of coil 7 feet 10". The data are as follows:

Length of coil 7'10" = 94" = 238.76 C.m. = $l$ ; diam. 8'3" = 99" = 251.46 C.m. = $d$

Turns wire No. 10 106 = $N$ (really 105 were wound + one turn loose)

Area $S = \frac{\pi d^2}{4} = 49662.52$ C.m. sq. From these data we

have $L = \frac{4\pi}{l} N^2 S = \frac{12.5664 \times 11236 \times 49662.52}{238.76} = 208 \times 12.5664 \times 11236 = 141196 \times 208 =$

$L = \underline{29,368,768}$ C.m. or $\underline{0.029369}$ H. approx. calculated

Now the readings were.

| E | J | ω | R |
|---|---|---|---|
| 110 | 6.05 | 880 | coil with cord 3.26 |
| 110 | 6.05 | 880 | cord 0.596 |
| 110 | 6.05 | 880 | coil alone 2.664 |

$\frac{E}{J} = 18.1818$ $\left(\frac{E}{J}\right)^2 = 330.58$

$R^2 = 7.097$

$\left(\frac{E}{J}\right)^2 - R^2 = 323.483$

$\omega^2 = 774400$

This gives $L^2 = \frac{323.483}{774400} = 0.000417721$

$L = \sqrt{0.000417721} = \underline{0.02042\ H}$ or $\underline{20,420,000}$ C.m.

Measurement shows a value much lower but this was to be expected as the turns are large also far apart ½". However the measurement is to be made again to be sure of the values.

*Colorado Springs*

Nov. 1, 1899

Measurement of inductance of new extra coil built chiefly for investigating propagation of waves through the ground and similar objects. Also to investigate further the behaviour of strong streamers.

The frame was made of light notched woodwork fastened to three strong wooden ings. Provision was made for 106 turns. The rings were 8 feet in diam. and taking further 1/2″ on each side for the crosspieces the total diameter of coil inside was 8′3″. The ength was 8 feet less 1 1/2″ on top and 1/2″ on bottom making total length of coil 7 feet 0″. The data are as follows:

ength of coil 7′ 10″=94″=238.76 cm=$l$; diam 8′ 3″=99″=251.46 cm=$d$

urns wire No.10 106=$N$ (really 105 turns wound+one turn loose)

rea $S=\frac{\pi d^2}{4}$=49,662.52 cm.sq. from these data we have

$$L=\frac{4\pi}{l}N^2 S=\frac{12.5664\times 11{,}236\times 49{,}662.52}{238.76}=208\times 12.5664\times 11{,}236$$

$$=141{,}196\times 208$$

$L$=**29,368,768 cm,** or **0.029369** H approx.

ow the readings were: *Calculated*

| | $I$ | $\omega$ | $R$ | |
|---|---|---|---|---|
| 10 | 6.05 | 880 | Coil with cord | 3.26 |
| 10 | 6.05 | 880 | cord | 0.596 |
| 10 | 6.05 | 880 | Coil alone | 2.664 |

$$\left(\frac{E}{I}\right)=18.1818\quad \left(\frac{E}{I}\right)^2=330.58$$

$$R^2=7.097$$

$$\left(\frac{E}{I}\right)^2-R^2=323.483$$

$$\omega^2=774{,}400$$

his gives $L^2=\frac{323.483}{774{,}400}$=0.000417721

$L=\sqrt{0.000417721}$=**0.02042 H** or **20,420,000 cm.**

easurement shows a value much lower but this was to be expected as the turns are large so 1/2″ apart. However this measurement is to be made again to be sure of the result.

*Colorado Springs*

Nov. 2, 1899

Readings were again taken today to ascertain the value found yesterday for inductance of new extra coil. The results were as follows:

| $E$ | $I$ | $\omega$ | $R$ | |
|---|---|---|---|---|
| 194 | 10.7 | 887 | 2.664 | average of three readings very closely agreeing. |

$$\left(\frac{E}{I}\right)=18.13 \qquad \left(\frac{E}{I}\right)^2=328.6969$$

$$R^2=\ \ 7.0969$$

$$\left(\frac{E}{I}\right)^2-R^2=321.60$$

$$L=\frac{\sqrt{321.6}}{887}=\frac{17.933}{887}$$

$L$=**0.0202176** henry or **20,217,600 cm.**

This is a value a little smaller than the one found yesterday but it is within the limits of variation of $\omega$.

**Note:** When the turns are far apart the ordinary formulas for calculating do not apply, and the measured value is the more inferior to the calculated value the greater the turns and the farther apart they are. When very far apart it is better to calculate inductance of one turn and multiply or, if they are not all alike, to calculate then separately and add up, making some allowance for mutual induction.

Secondary last form, two wires No. 10 in multiple 17 turns on frame described on another occasion. To test the values before found for inductance and mutual induction coefficient readings were again taken today. For secondary inductance:

| $E$ | $I$ | $\omega$ | $R$ | |
|---|---|---|---|---|
| 138 | 16.5 | 887 | 1.382 | The first two readings were in all probability the best and they are taken. |
| 138 | 16.5 | | | |
| 136 | 16.3 | 875 | | |
| 134.5 | 16.2 | | | |

From above:

$$\frac{E}{I}=8.364 \qquad \left(\frac{E}{I}\right)^2=69.9565 \qquad \left(\frac{E}{I}\right)^2-R^2=68.0465$$

$$L=\frac{\sqrt{64.0465}}{887}=\frac{8.003}{887}=\mathbf{0.009023\ H\ or\ 9{,}023{,}000\ cm.}$$

This is smaller than before found because the turn before last was wound a little higher up as at first sparks would break through. It is to be measured once more however.

Readings for *Mutual Induction* Coefficient.

**Two primary turns in series:**

| Current through primary two turns in series | Volts on secondary | |
|---|---|---|
| $I$ | $E$ | $\omega$ |
| 45.4 | 34 | 880 |
| 45.4 | 34 | ,, |
| 45.4 | 34 | ,, |

From this $E=M\omega I$, $M=\dfrac{34\times10^9}{880\times45.4}=$ **851,021 cm.**

Readings with current through the secondary gave:

| Current through secondary | Volts on primary two turns series | $\omega$ |
|---|---|---|
| 17.8 | 13.4 | 872 } over |
| 17.8 | 13.4 | ,, } |

From later readings $M=\dfrac{13.4\times10^9}{17.8\times872}=$ **863,313 cm.**

This is a little larger probably due to variation of $\omega$. Readings were now taken for each of the primary turns separate with the following results:

**Upper primary turn,** nearer to secondary:

| Current through secondary | E.m.f. on primary | $\omega$ |
|---|---|---|
| 17.9 | 6.9 | 872 average three readings |

From this $M_{\text{upper pr.}}=\dfrac{6.9\times10^9}{17.9\times872}=$ **442,059 cm.**

| Current through primary | E.m.f. on secondary | $\omega$ |
|---|---|---|
| 30.1 | 11.8 | 880 average three readings |

$$M_{\text{upper. pr.}}=\frac{11.8\times10^9}{30.1\times880}=\mathbf{445{,}484\ cm.}$$

**Lower primary turn.** Readings were as follows:

| Current through primary | E.m.f. secondary | $\omega$ |
|---|---|---|
| 30.1 | 11.1 | 880 average three readings |
| Current through secondary | E.m.f. primary | |
| 17.9 | 6.4 | 880 average three readings |

From first set readings:

$$M_{\text{lower pr.}} = \frac{11.1 \times 10^9}{30.1 \times 880} = 419{,}060 \text{ cm.}$$

From second set readings:

$$M_{\text{pr. lower}} = \frac{6.4}{17.9 \times 880} = 406{,}300 \text{ cm.}$$

**For two primary turns multiple**

| Current through primaries | E.m.f. secondary | $\omega$ |
|---|---|---|
| 29.2 | 11.25 | 880 average three readings |
| Current through secondary | E.m.f. primaries | |
| 17.9 | 6.7 | 880 average three readings |

From first set of readings:

$M_{2\ \text{prim. multiple}} = 437{,}811$ cm

From latter readings:

$M_{2\ \text{pr. multiple}} = 425{,}343$ cm

*Colorado Springs*

Nov. 3, 1899

Investigation for the purpose of ascertaining the influence of elevation upon the capacity of a conductor connected to a vibrating system as before used, continued:

The coil of 346 turns, No. 10 wire wound on drum 14″ diam., 8 feet long was again used. The spark wires were as before No. 26 guttapercha covered, 24 feet long each. The readings were as follows:

| Capacity in primary circuit *total* | Inductance in primary turns reg. coil+conn. | Length of vertical wire attached to free terminal of excited coil | Analyzing spark on terminals of excited coil |
|---|---|---|---|
| $\frac{(3 \times 36) - 2}{2} = 53$ bottles $=$ $= 0.0479$ mfd | 7 1/8+conn. | 45 feet | 3 3/8″ |
| 0.0479 mfd | 6 3/8+ ,, | 36 ,, | 3 3/8″ |
| ,, | 5 3/4+ ,, | 27 ,, | 3 3/8″ |
| | 5 3/16+ ,, | 18 ,, | 3 1/4″ |

**Note:** As repeatedly observed, the first addition of a small length of wire to a coil generally produces a great effect but a certain small length being bypassed the increase per unit of length becomes more gradual.

Experiments with coil 346 turns on drum 14″ diam. with the view of investigating influence of elevation upon the capacity of a body connected to earth continued. This time in connection with the vertical wire a ball 30″ diam. was used in the manner before described.

**Coil with spark wires alone**

| Capacity in primary circuit *total* | Turns in regulating coil+connections } Inductance | Analyzing spark on terminals of excited coil |
|---|---|---|
| $\frac{(3\times 36)-2}{2}$ =53 bottles= =0.0479 mfd | 3 5/8 +conn. | 3 1/8″ |
| **Coil with 50 feet wire No. 10 vertical** | | |
| 0.0479 mfd | 7 3/4+conn. | 4″ |
| **Coil with ball 30″ diam. lowest position** 10′3″ from center to ground | | |
| 0.0479 mfd | 8 1/2+conn. | 4 1/8″ |
| **Coil with ball mean position** 33′9″ from center to ground | | |
| 0.0479 mfd | 8 7/8+conn. | 4 1/4″ |
| **Coil with ball highest position** 57′3″ from center to ground | | |
| 0.0479 mfd | 9 1/4+conn. | 4 3/8″ |

**Note:** The excitation in this and previous case was as before described by connecting the lower terminal of coil to that terminal of the condensers (primary) which was connected to small adjustable spark gap, specially made for this purpose, to earth.

It would be desirable in these tests to do away with the spark wires as these are apt to introduce errors in the estimates of capacity. Experiments were made with new extra coil to see how close the maximum rise could be ascertained without any spark wires, merely by observing the streamers. For this purpose the extra coil was excited from the secondary of oscillator as in some previous instances. First the extra coil was tuned with spark wires, then the upper wire which is the only one of importance was taken off and the system again tuned. The results were as follows:

**New Extra coil with Spark wires** Guttapercha No. 26, 24 feet long

| Capacity in primary circuit total | | Inductance in primary circuit Turns of regul. coil+connections |
|---|---|---|
| bottles | mfd | |
| (8 × 36) – 2 | | |

**New Extra coil without upper Spark wire**

$\frac{(8 \times 36) - 2}{2} = 143$ bottles $= 0.1287$ 5 5/8 + connections

*Colorado Springs*

Nov. 4, 1899

*Measurement of inductance of primaries.*

Another series of readings were taken with the object of closely determining the inductance of the primary turns. This time a different dynamo was supplying the current. The speed was kept very constant. The readings were as follows:

| Current | Electromotive force across two primaries in series | $\omega$ |
|---|---|---|
| 345° = 58.8 | 12 a trifle less | 880 |
| 345° = 58.8 | 12 ,, | ,, |
| 345° = 58.8 | 12 ,, | ,, |

Allowing a little for zero displacement on voltmeter the average is very closely:

| $I$ | $E$ | $\omega$ | $R$ two primary turns in series |
|---|---|---|---|
| 58.8 | 11.95 | 880 | 0.004 ohm. |

This gives $\frac{E}{I} = 0.2032$ $\left(\frac{E}{I}\right)^2 = 0.04129$ $R^2 = 0.000016$

Since $R^2$ is entirely negligible against $\left(\frac{E}{I}\right)^2$ we have:

$$L = \frac{E}{I\omega} = \frac{11.95}{51,744} = 0.000230945 \text{ henry}$$

or **230,945 cm.**

This would give for one primary turn approximately

0.000057736 henry or **57,736 cm.**

The value previously found was 56,400 cm.
Reading of today would appear more reliable.

*Colorado Springs*

Nov. 5, 1899

Capacity of structure of iron pipes, before described, computed:

**7″ pipe:** Outside diam. 7.625″=19,3673 cm=$d$

length of pipe with cap=$l$=23′ 4″=280″=811.2 cm=$l$

$$C_1 = \frac{l}{2\log_e \frac{l}{r}} = \frac{811.2}{2\times 4.42313} \qquad r=9.6837 \qquad \frac{l}{r}=83.77$$

$$\mathbf{C_1=91.7\ cm.} \qquad \log_e \frac{l}{r}=1.9231\times 2.3=4.42313$$

**6″ pipe:** Outside diam.=6.625″=16.8275 cm=$d$

length of pipe 18′ 2″=218″=553.72 cm=$l$

$$C_2 = \frac{l}{2\log_e \frac{l}{r}} = \frac{553.72}{2\times 4.182} \qquad r=8.4138 \qquad \frac{l}{r}=65.81$$

$$\mathbf{C_2=66.2\ cm.} \qquad \log_e \frac{l}{r}=1.818292\times 2.3=4.182$$

**5″ pipe:** Outside diam. 5.563″=14.13 cm=$d$

length of pipe 18′ 4 1/2″=220.5″=560.07 cm=$l$

$$C_3 = \frac{l}{2\log_e \frac{l}{r}} = \frac{560.07}{2\times 4.368} \qquad r=7.065 \qquad \frac{l}{r}=79.27$$

$$\mathbf{C_3=64.11\ cm.} \qquad \log_e \frac{l}{r}=1.89911\times 2.3=4.368$$

**4″ pipe:** Outside diam. 4.5″=11.43 cm=$d$

length of pipe 15′ 7 1/4″=187.25″=475.615 cm.=$l$

$$C_4 = \frac{l}{2\log_e \frac{l}{r}} = \frac{475.615}{8.832} \qquad r=5.715 \qquad \frac{l}{r}=83.22$$

**3 1/2″ pipe:** Outside diam. 4″=10.16 cm=$d$

length of pipe 19′ 3 1/4″=231.25″=587.375 cm=$l$

$$C_5 = \frac{l}{2\log_e \frac{l}{r}} = \frac{587.375}{9.49} \qquad r = 5.08 \qquad \frac{l}{r} = 115.6$$

$$C_5 = \mathbf{61.9\ cm.} \qquad \log_e \frac{l}{r} = 2.062958 \times 2.3 = 4.745$$

**3″ pipe:** Outside diam. 3.5″=8.89 cm=$d$

length of pipe 18′ 4 3/4″=220.75″=560.7 cm=$l$

$$C_6 = \frac{l}{2\log_e \frac{l}{r}} = \frac{560.7}{2 \times 4.83} \qquad r = 4.445 \qquad \frac{l}{r} = 126.1$$

$$C_6 = \mathbf{58.05\ cm.} \qquad \log_e \frac{l}{r} = 2.1 \times 2.3 = 4.83$$

**2 1/2″ pipe:** Outside diam. 2.875″=7.3 cm=$d$

$$\left.\begin{array}{l}\text{length of pipe } 8'\ 1/4'' \\ \quad ,, \quad \text{nipples } 7\ 3/4''\end{array}\right\} 8'\,8'' = 104'' = 264.16 \text{ cm} = l$$

$$C_7 = \frac{l}{2\log_e \frac{l}{r}} = \frac{264.16}{2 \times 4.276} \qquad r = 3.65 \qquad \frac{l}{r} = 72.37$$

$$C_7 = \mathbf{30.89\ cm.} \qquad \log_e \frac{l}{r} = 1.859 \times 2.3 = 4.276$$

from above we have *total capacity* of structure

| $C$: | | |
|---|---|---|
| | 7″ pipe with cap | 91.7 cm. |
| | 6″ pipe | 66.2 ,, |
| | 5″ pipe | 64.11 ,, |
| | 4″ pipe | 53.85 ,, |
| | 3 1/2″ pipe | 61.9 ,, |
| | 3″ pipe | 58.05 ,, |
| | 2 1/2″ pipe | 30.89 ,, |
| | Ball 30″ diam. | 38.1 ,, |
| | Total Capacity | $C$= 464.8 cm. |

Note: This supposes of course that all these capacities are connected in multiple.

*Colorado Springs*

Nov. 6, 1899

*Determination* of el. st. *capacity* of the structure of iron pipes *by measurement.*

The method previously employed for such a purpose was again used. The coil described on a former occasion, wound on a drum of 10 5/16" and having 550 turns was excited from a vibrating primary system and the maximum resonant rise obtained with only the spark wires attached to the terminals of the coil. Then the upper terminal of the latter was connected to the structure and the maximum rise again obtained. From the two known periods of the primary system and the self-induction of the coil the capacity of the structure was then computed. In order to avoid errors due to the capacity of the wires connected to the coil the precaution was taken to make no change which would in any considerable way affect the result. Thus, when the vibration of the coil with only the spark wires was determined the wire which was to be later connected to the structure was likewise fastened to the upper terminal of the coil in a position such that in the second experiment or series of experiments it was only necessary to tilt the wire to bring it in contact with the structure. If this precaution would not be observed the error introduced by the connecting wire might be — and in fact it would generally be — considerable. The adjustments were first made with the spark wires and the wire which was to be connected to the structure, this wire being placed vertically and at a distance of about four feet from the latter. The maximum rise was observed on the terminals of the excited coil with:

| Capacity in primary circuit total | Turns in regulating coil | Spark analyzing on terminals |
|---|---|---|
| $\frac{(8\times 36)-2}{2}=143$ Bottles or 0.1287 mfd | 2 1/8 | 2 5/8" |

Now the wire was tilted and brought in contact with the structure and resonant maximum rise was observed with:

| | | |
|---|---|---|
| $\frac{(8\times 36)-2}{2}=143$ Bottles$=0.1287$ mfd | 17 1/2 | 2 5/8" |

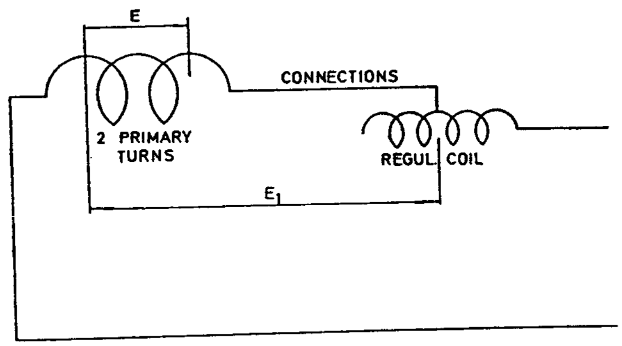
To determine more satisfactorily the self-induction in both the primary vibrations readings were taken in the following manner. The two primary turns, connections to breaks and condensers and the regulating coil were all connected in series — the breaks and condensers being of course bridged by stout and short wires (No. 2 being used) and readings of e.m.f. across the two primary turns were first taken and then across the two primaries plus connections and turns in the regulating coil as were used in the two instances. Since the resistances were entirely negligible with respect to the inductances it was only necessary to make the ratio of the e.m.f. in two instances to determine the inductance of the connections and turns from the known inductance of the two primary turns which was carefully determined before. As the readings were taken practically at the same moments across the primaries alone and across the primaries connections and turns $\omega$ could not vary perceptibly, and to make sure of that the readings were taken repeatedly. The current passed through the inductances also remaining the

The results in the first case were as follows:

$$\left.\begin{aligned} E_1 &= 10.4 \text{ volts} \\ E &= 10 \quad \text{volts} \end{aligned}\right\} \quad \begin{aligned} &I \text{ and } \omega \\ &\text{the same.} \end{aligned}$$

In the second case:

$$\left.\begin{aligned} E_1 &= 13.15 \text{ volts} \\ E &= 10.3 \quad \text{,,} \end{aligned}\right\} \quad \begin{aligned} &I \text{ and } \omega \\ &\text{the same.} \end{aligned}$$




Calling now $L$ the inductance of the two primary turns in series and $L_1$ that of the two primaries+connections+2 1/8 turns of the regulating coil we have in first case:

$$\frac{E_1}{E} = \frac{L_1}{L} \text{ and } L_1 = \frac{E_1}{E} L$$

Now $L$ was previously determined to be 230,945 cm, hence

$$L_1 = \frac{104}{100} \times 230{,}945 = 240{,}183 \text{ cm.}$$

From this inductance of the connections+2 1/8 turns of the regulating coil is $L_1 - L =$ $= 9238$ cm.

In the second case we have similarly

$$L_2 = \frac{13.15}{10.3} \times 230{,}945 = 294{,}847 \text{ cm.}$$

$L_2$ being inductance of two primaries+connections+17 1/2 turns of regulating coil.

Hence the inductance of the connections and the turns (17 1/2) included is $L_2 - L =$ $= 63{,}902$ cm.

From these data the capacity of the structure can now be estimated as follows: In the first case the primary vibration was

$$T = \frac{2\pi}{10^3}\sqrt{\frac{9238}{10^9} \times 0.1287}$$

In the second case the primary vibration was

Calling now $C_s$ the capacity of the excited system when the structure was not attached to it, and $C_s'$ that when this was the case we have:

$$T_1 = \frac{2\pi}{10^3}\sqrt{C_s L'} = \frac{2\pi}{10^3}\sqrt{\frac{9238}{10^9} \times 0.1287}$$

and

$$T_2 = \frac{2\pi}{10^3}\sqrt{C_s' L'} = \frac{2\pi}{10^3}\sqrt{\frac{63{,}902}{10^9} \times 0.1287}$$

$L'$ being the inductance of the excited coil. $L'$ was previously measured and found to be $L' = 18{,}650{,}000$ cm. Now from above:

$$C_s = \frac{9238 \times 0.1287}{10^9 \times \frac{18{,}650{,}000}{10^9}} = \frac{9238 \times 0.1287}{18{,}650{,}000};$$

and

$$C_s' = \frac{63{,}902 \times 0.1287}{18{,}650{,}000}; \quad \frac{C_s'}{C_s} = \frac{63{,}902}{9238}; \quad C_s' = C_s \frac{63{,}902}{9238}$$

$C_s$ expressed in centimeters is:

$$C_s = \frac{9238 \times 0.1287 \times 9 \times 10^5}{1865 \times 10^4} = \frac{11.583 \times 9238}{1865} = 57.375$$

from this $C_s' = \frac{63902}{9238} \times 57.375 = 6.92 \times 57.375 = \mathbf{397.03\ cm.}$

$$C = C_s' - C_s = \mathbf{339.655\ cm.}$$

This is a result inferior to the calculated value but it was to be expected as before stated since it can not be correct to assume that all pipes are connected in multiple unless the vibration is very slow. Another coil is to be used with an inductance much higher so as to examine the truth of this opinion. There is, however, a possibility that the reading, when the structure was attached to the excited coil, was too low. In this case namely, the tuning is *not sharp* owing to the large capacity of the system but when the structure is *not* attached it is quite sharp, hence if there is any error in the adjustment of the circuits it can be only then when the structure was connected. This is to be investigated also. A slight error might have been also caused by the wire which connected the coil to the structure, for although this wire was placed at a distance of 4 feet with its nearest point there might have been enough influence exerted by the structure to make the reading with the spark wires alone larger. This will be ascertained. From previous tests on the increase of capacity with elevation I should expect to find the capacity of the structure much larger than the calculated value.

On the present occasion readings were also taken with the view of determinig the inductance of the connections alone+flexible cable on regulating coil+1/2 turn of regulating coil. This namely is the lowest value which it is possible to give with the regulating to foregoing and calling $L_3$ the inductance of the two primaries+connections+flexible cable+1/2 turn of regulating coil:

$$L_3 = \frac{105}{102} \times L = \frac{105}{103} \times 230{,}945 = 237{,}738 \text{ cm.}$$

Hence the inductance of all these mentioned connections is $L_3 - L = 237{,}738 - 230{,}945 =$

$= 6793$ cm, for $\left\{\begin{array}{l}\text{connections proper}\\ \text{1/2 turn regulating coil,}\\ \text{flexible cable in reg. coil.}\end{array}\right.$

Note: A small error is often caused by the changing position of the flexible cable which makes the readings for a small number of turns *larger* (slightly).

*Colorado Springs*

Nov. 7. 1899

Further experiments for the purpose of ascertaining the capacity of the structure of the iron pipe by resonance analysis. Two sets of readings were taken: one set with new extra coil the other with coil 346 turns wire No.10 on drum 14″ diam. The readings were as follows:

**With new extra coil**

| Capacity in primary exciting circuit *total:* | Inductance in primary circuit. Turns of regulating coil+conn. | Analyzing spark on *terminals of* excited coil. |
|---|---|---|
| $\frac{(8 \times 36) - 2}{2}$ = 143 bottles = 0.1287 mfd | 22+conn. | 2 5/16″ |
| $\frac{(8 \times 36) - 2}{2}$ = „ = 0.1287 mfd | 8+ „ | 3 3/4″ |

**With experimental coil described**

| | | |
|---|---|---|
| $\frac{(3 \times 36) - 2}{2}$ = 53 bottles = 0.0477 mfd | 15.75+conn. | 4″ |
| $\frac{(3 \times 36) - 2}{2}$ = „ = 0.0477 mfd | 3.5+ „ | 3 1/8″ |

*Note: The first readings are of course *with*, the second *without* structure in each case of the primary and secondary circuits. With the same capacity as in the last case resonance was obtained with spark wires alone:

$\frac{(3 \times 36) - 2}{2} = 35$ bottles $= 0.0477$ mfd 8 7/8 3 1/4″

This for *future reference.*

Returning to the two sets of observations it is to be noted that *one* turn of the new extra coil had been taken off and allowance should be made for this.

Let the primary vibration in the first case be $T_{p1}$ and the corresponding secondary vibration $T_{s1}$ then $T_{p1} = T_{s1}$. Similarly for the second reading with the extra coil when the structure was not attached to the coil. Calling the respective vibration $T_{p2}$ and $T_{s2}$ we have $T_{p2} = T_{s2}$. Now

$$T_{p1} = \frac{2\pi}{10^3}\sqrt{L_{p1} \times C} \quad \text{and} \quad T_{p2} = \frac{2\pi}{10^3}\sqrt{L_{p2} \times C}$$

where $L_{p1}$ and $L_{p2}$ designate the inductances of the primary circuit in the two cases. From this

$$\frac{T_{p1}}{T_{p2}} = \sqrt{\frac{L_{p1}}{L_{p2}}}$$

as useful relation to remember.

While the self-induction was varied in the primary circuit, and the capacity remained the same, in the secondary it was just the opposite, the self-induction remaining the same and the capacity being varied. Calling now the capacity of the excited system with the structure $C_{s1}$ and without the structure $C_{s2}$ (that of coil with spark wires alone) we have by analogous reasoning:

$$\frac{T_{s1}}{T_{s2}} = \sqrt{\frac{C_{s1}}{C_{s2}}} = \frac{T_{p1}}{T_{p2}} = \sqrt{\frac{L_{p1}}{L_{p2}}} \quad \text{or} \quad \frac{C_{s1}}{C_{s2}} = \frac{L_{p1}}{L_{p2}}.$$

This is also a convenient equation and useful to bear in mind. In cases when the capacity in the excited system is very often varied it is only necessary to determine the first capacity with which the series of experiments was begun to know all the other values from the known inductances of the primary circuit in two consecutive experiments. But when there are only two values to be determined, as in the present instance, they can be at once calculated from the known primary vibrations.

In the present instance, adopting this procedure we have:

$$T_{p1} = \frac{2\pi}{10^3}\sqrt{0.1287 \times 0.000079} \quad \text{and} \quad L_{p1} \begin{cases} \text{Connections } +22 \text{ turns:} \\ = 79{,}000 \text{ cm.} = 0.000079 \text{ H} \end{cases}$$

$$T_{p2} = \frac{2\pi}{10^3}\sqrt{0.1287 \times 0.00002526} \qquad L_{p2} \begin{cases} \text{Connections } +8 \text{ turns reg. coil} \\ = 25{,}260 \text{ cm.} = 0.00002526 \text{ H} \end{cases}$$

$$T_{p1} = T_{s1} = \frac{2\pi}{10^3}\sqrt{C_{s1} \times 0.02}$$

$2\pi$

Inductance of extra coil before measured was 0.02042 henry. This owing to one turn less without *change of length* should be reduced to ratio $\left(\frac{105}{106}\right)^2$ or about 2% making the inductance very approx. 20,000,000 cm. or 0.02 henry.

From the above:

$$\frac{2\pi}{10^3}\sqrt{C_{s1}\times 0.02}=\frac{2\pi}{10^3}\sqrt{0.1287\times 0.000079}$$

and

$$C_{s1}=\frac{0.1287\times 0.000079}{0.02}\text{ mfd,}$$

or in centimeters:

$$C_{s1}=\frac{9\times 10^5\times 0.1287\times 0.000079}{0.02}=\mathbf{457.5}\text{ cm.}$$

Similarly we have

$$C_{s2}=\frac{0.1287\times 0.00002526}{0.02}\text{ mfd, or}$$

$$C_{s2}=\frac{9\times 10^5\times 0.1287\times 0.00002526}{0.02}=\mathbf{146.29}\text{ cm.}$$

This would give for the capacity of the structure according to this method only $C_{s1}$—$C_{s2}$= =457.5—146.29=**311.21 cm.**

This inferior result I attribute to the fact that the capacity is partially to be taken as *distributed,* owing to the length of the structure. But determining by the same method with a vibration which would be much slower this error should be very small.

Taking now the values for the set of readings with the experimental coil of 346 turns we have:

$$T'_{p1}=\frac{2\pi}{10^3}\sqrt{0.0377\times 0.00005486}\quad\text{and}\quad L_{p1}=\text{connections}+15.75\text{ turns}$$
$$=54{,}860\text{ cm.}=0.00005486\text{ H}$$

$$T'_{p2}=\frac{2\pi}{10^3}\sqrt{0.0377\times 0.00001116}\qquad L_{p2}=\text{conn.}+3\ 1/2\text{ turns}=$$
$$=11{,}160\text{ cm.}=0.00001116\text{ H}$$

The inductance of the experimental coil measured being 6,040,000 cm, or 0.00604 henry we have:

$$T'_{s1}=\frac{2\pi}{10^3}\sqrt{0.00604\times C'_{s1}}\quad\text{and}\quad T'_{s2}=\frac{2\pi}{10^3}\sqrt{0.00604\times C'_{s2}}$$

from these relations follows:

$$C'_{s1}=\frac{0.0477\times 0.00005486}{0.00604}\text{ mfd. and}$$

Hence

$$C'_{s1} - C'_{s2} = \frac{0.0477}{0.00604} \times (0.00005486 - 0.00001116)$$

$$= \frac{0.0477}{0.00604} \times 0.0000437 \text{ mfd, or}$$

$$C'_{s1} - C'_{s2} = \frac{9 \times 0.0477 \times 4.37}{0.00604} \text{ centimeters} = \mathbf{310.6\ cm.}$$

**very nearly the same value.**

It is to be expected that the value found with a quicker vibrating system should be smaller since then the structure begins to act not as one condenser but as a series of condensers or distributed capacity, all parts not being charged at the same time.

This method of determining the capacity implies therefore to be quite correct a *slow* vibration and, furthermore, negligible capacity in the vibrating system itself and also that the body the capacity of which is determined should not be of too great length since this must cause errors.

From reading with coil of 550 turns it follows, since the capacities both in the primary and secondary circuits remained the same, that the inductances in the primary and inductances in the secondary or excited circuit bore the same ratio, that is:

$$\frac{\text{Ind. 8 7/8 turns + conn.}}{\text{Ind. 3.5 turns + conn.}} = \frac{\text{Ind. coil 550 turns}}{\text{Ind. coil 344 turns}}$$

Ind. of coil 550 turns was: 18,650,000

Ind. of coil 344 turns was: 6,040,000

Hence $\frac{\text{Ind. 8 7/8 turns}}{\text{Ind. 3 1/2 turns}} = \frac{1865}{604}$ **This for later comparison.**

*Colorado Springs*

Nov. 8, 1899

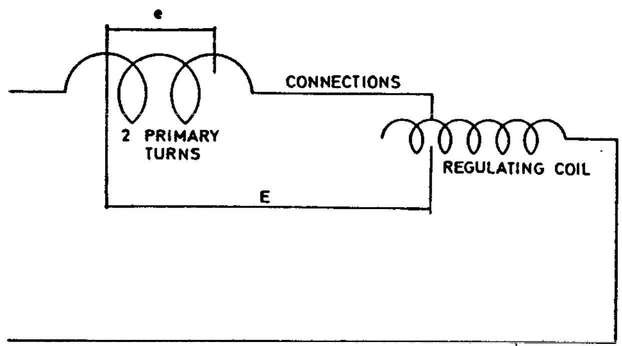
*Table* of *inductances* prepared from preceding readings.

| | | |
|---|---|---|
| Two primary turns in series | 230,945 cm. | 0.000230945 H |
| One of the primary turns | 57,736 „ | 0.000057736 „ |
| All connections to condensers and breaks *as used* | 5004 „ | 0.000005004 „ |
| All connections plus one half turn of reg. coil (first turn) | 5774 „ | 0.000005774 „ |
| All connections plus the whole first turn of reg. coil | 6544 „ | 0.000006544 „ |
| „ „ 1 1/2 „ „ | 7314 „ | 0.000007314 „ |
| „ „ 2 „ „ | 8084 „ | 0.000008084 „ |
| „ „ 2 1/2 „ „ | 8854 „ | 0.000008854 „ |
| „ „ 3 „ „ | 10,009 „ | 0.000010009 „ |
| „ „ 3 1/2 „ „ | 11,164 „ | 0.000011164 „ |
| „ „ 4 „ „ | 12,319 „ | 0.000012319 „ |
| „ „ 4 1/2 „ „ | 13,474 „ | 0.000013474 „ |
| „ „ 5 „ „ | 15,158 „ | 0.000015158 „ |
| „ „ 5 1/2 „ „ | 16,842 „ | 0.000016842 „ |
| „ „ 6 „ „ | 18,526 „ | 0.000018526 „ |
| „ „ 6 1/2 „ „ | 20,210 „ | 0.000020210 „ |
| „ „ 7 „ „ | 21,894 „ | 0.000021894 „ |
| „ „ 7 1/2 „ „ | 23,578 „ | 0.000023578 „ |
| „ „ 8 „ „ | 25,262 „ | 0.000025262 „ |
| „ „ 8 1/2 „ „ | 26,946 „ | 0.000026946 „ |
| „ „ 9 „ „ | 28,870 „ | 0.000028870 „ |
| „ „ 9 1/2 „ „ | 30,794 „ | 0.000030794 „ |
| „ „ 10 „ „ | 32,718 „ | 0.000032718 „ |
| „ „ 10 1/2 „ „ | 34,642 „ | 0.000034642 „ |

* This table is close enough for all general estimates.

After 10 1/2 turns the increase is 3850 cm. per turn so that the inductance of 10 1/2+$n$ turns+conn. will be 34,642+$n\times$3850 cm. With the entire coil in, there are 23 1/2 turns having 84,692 cm. or 0.000084692 H.

In order to test the accuracy of the preceding measurements, readings of the e.m.f. across the two primaries, connections and the regulating coil — all joined in series — were taken repeatedly and in as rapid a succession as was found practicable, the number of the turns of the regulating coil being varied after each set of readings. The diagram below shows the connections of the various inductances while the readings, reduced to the same




| Number of turns of the regulating coil included in circuit. | E.m.f. across two primary turns plus the connections, plus flexible cable+one half of one turn reg. coil | | | | | Difference of e.m.f. between successive readings: |
|---|---|---|---|---|---|---|
| | first series of readings | second series | third series | fourth series | average | |
| 23 1/2 | 15.873 | 15.928 | 15.928 | 15.928 | 15.914 | ω was in these readings smaller than 880. |
| 22 1/2 | 15.706 | 15.706 | 15.706 | 15.706 | 15.706 | 0.208 |
| 20 1/2 | 15.318 | 15.263 | 15.34 | 15.318 | 15.310 | 0.396 |
| 18 1/2 | 14.929 | 14.8185 | 14.929 | 14.929 | 14.901 | 0.399 |
| 16 1/2 | 14.4855 | 14.4855 | 14.4855 | 14.4855 | 14.4855 | 0.4155 |
| 14 1/2 | 14.119 | 14.0415 | 14.1525 | 14.097 | 14.102 | 0.3835 |
| 12 1/2 | 13.764 | 13.7085 | 13.764 | 13.764 | 13.75 | 0.352 |
| 10 1/2 | 13.3755 | 13.3755 | 13.3755 | 13.3755 | 13.3755 | 0.3745 |
| 8 1/2 | 13.0425 | 12.9537 | 13.009 | 13.0425 | 13.012 | 0.3635 |
| 6 1/2 | 12.7095 | 12.654 | 12.7095 | 12.7095 | 12.6956 | 0.3164 |
| 4 1/2 | 12.3765 | 12.3765 | 12.3765 | 12.3765 | 12.3765 | 0.3191 |
| 2 1/2 | 12.1545 | 12.1212 | 12.1875 | 12.1545 | 12.1544 | 0.2221 |
| 1/2 | 12.00 | 12.00 | 12.00 | 12.00 | 12.00 | 0.1544 |

Note: When reduced to the same e.m.f. across the two primaries and connections, 1/2 turn and flexible cable the average values agree fairly well with the readings before recorded. The table prepared on the bases of the values before found will be accurate enough for all ordinary estimates. Both sets of readings show that there is about 0.2 volt variation per turn, the few first turns excepted.

Following readings were taken today for the purpose of putting together a table of the inductances of the various turns of the regulating coil. The machine was specially run and all care was taken to get the readings as close as practicable. The method used in a previous case was again adopted which consisted in reading the e.m.f. across the two primary turns in series and simultaneously the e.m.f. across the two primary turns+ +connections+the turns in the regulating coil. The resistances as before stated being entirely negligible, the inductance in each case was given by the ratio of the e.m. forces and the known inductance of the two primary turns. By this method the error which might have been caused by a variation of $\omega$ which could only be determined by taking the speed of the generator, the apparatus for the more exact determination of this quantity being unfortunately left in New York. The results are indicated in the following table:

| E.m.f. across two primary turns in series | E.m.f. across two primary turns+ connections+turns of the regulating coil | Number of turns reg. coil | $I$ | $\omega$ | Increase of e.m.f. from step to step |
|---|---|---|---|---|---|
| 12.00 | 12.3 | 1/2 | 58.8 | 880 | |
| 12.00 | 12.45 | 2 1/2 | 58.8 | ,, | 0.15 |
| 12.00 | 12.70 | 4 1/2 | 58.8 | ,, | 0.25 |
| 12.00 | 13.05 | 6 1/2 | 58.8 | ,, | 0.35 |
| 12.00 | 13.40 | 8 1/2 | 58.8 | ,, | 0.35 |
| 12.00 | 13.80 | 10 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 14.20 | 12 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 14.60 | 14 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 15.00 | 16 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 15.40 | 18 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 15.80 | 20 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 16.20 | 22 1/2 | 58.8 | ,, | 0.40 |
| 12.00 | 16.40 | 23 1/2 | 58.8 | ,, | 0.20 |

This shows an increase per turn of about 0.20 V, except the few first turns.

*Colorado Springs*

Nov. 9, 1899

In some experiments it was necessary to use vibrations of lower frequencies and this strong sparking on the secondary and changing reaction on the primaries it was necessary to join the ends of the secondary. Readings were taken to determine more closely the inductance of the primaries with the secondary closed.

The results were as follows:

| Current | E.m.f. across two primary turns in series | | $\omega$ |
|---|---|---|---|
| 58.80 | | 8.75 | 880 |
| 58.40 | | 8.5 | ,, |
| 58.00 | | 8.33 | ,, |
| Average 58.40 | Average | 8.45 (with allowance for zero displacement) | 880 |

With the secondary open the readings were exactly as before:

| | | |
|---|---|---|
| 58.8 | 11.95 | 880 |

Reduced to same current for both cases the readings with secondary closed become:

| | | |
|---|---|---|
| 58.8 | 8.5 | 880 |

The inductance of two primary turns as before found 230,945 cm.$=L$. We have for their inductance with *secondary closed* $\frac{8.5}{11.95}L=$ **164,270 cm.**

With both primaries in multiple it ought to be **41,068 cm.** approx.

According to previous estimates the mutual induction coefficient with two primaries in series was: approximately 850,000 cm. The inductance of the secondary was found: 9,568,000 cm. last time, say average of two last determinations 9,560,000 cm. From this data we have for inductance with secondary closed:

$$L-\frac{M^2}{N}=230{,}945-\frac{85^2\times 10^8}{956\times 10^4}=230{,}945-\frac{85^2\times 10^4}{956}=230{,}945-75{,}575=\mathbf{155{,}370\ cm.}$$

These readings above do not quite agree with the result calculated, but I think this only indicates some action of secondary on the primary when the former *is open*, or else the mutual induction coeff. measured a little *too high*. This **very likely.**

As it was not always possible to get along with the primaries alone when using them as inductances two self-induction coils were provided, one wound with wire No. 6, the other with wire No. 2 both on a drum of 5″ diam. The particulars relating to both of these coils will be given below. To ascertain approximately their inductances readings were taken by joining them successively in circuit with the two primary cables in series and taking the e.m.f. across, this giving the inductance of each of them approximately from the ratio of the e.m.f. and the known inductance of the primaries neglecting of course the resi-

*For coil wound with No. 6 wire:*

| E.m.f. across two primary turns+coil all in series | E.m.f. across two primaries in series alone | Current | $\omega$ |
|---|---|---|---|
| 14.5 | 6.4 | 30.9 | 880 |
| 14.5 | 6.4 | 30.9 | 880 |
| 14.5 | 6.4 | 30.9 | 880 |

*For coil with No. 2 wire:*

| | | | |
|---|---|---|---|
| 13.5 | 8.2 | 40.1 | 880 |
| 13.5 | 8.2 | 40.1 | 880 |
| 13.5 | 8.2 | 40.1 | 880 |

This would give approximately inductances of coil No. 6 wire:

$$l = \frac{14.5}{6.4} \times 230{,}945 - 230{,}945 = \frac{8.1}{6.4} \times 230{,}945 = \mathbf{292{,}290\ cm,}$$

**Coil No. 6 wire**

and for coil No. 2 wire

$$l_1 = \frac{13.5}{8.2} \times 230{,}945 - 230{,}945 = \frac{5.3}{8.2} \times 230{,}945 = \mathbf{149{,}340\ cm,}$$

**Coil No. 2 wire**

These figures were first utilised then separate readings were taken. All the particulars of these coils and the measured and calculated values are as follows:

*Coil wound with No. 6 wire:*
length of wound part 38.75″=98.425 cm, drum 5″=12.7 cm. 129 turns

Thickness of wire with insulation $\frac{98.425}{129}$ cm. Thickness of bare wire=0.162″=0.41148 cm.

Thickness of two insulations $\frac{98.425}{129}$—0.41148=0.763—0.4115=0.3515 cm. This is to be added to the core 12.7 cm diam. making total diam. 13.0515 cm.

To calculate inductance we have therefore the following data:

$$d = 13.0515\text{ cm},\quad l_1 = 98.425\text{ cm},\quad N = 129,\quad N^2 = 16641,\quad S = \frac{\pi}{4} d^2 = 133.786\text{ cm.sq.}$$

This gives $l = \frac{12.5664}{98.425} \times 16{,}641 \times 133.786 = \mathbf{284{,}247\ cm.}$

Now the readings to estimate from were:

| e.m.f. | Current | $\omega$ | $R$ calculated approx. 180 feet wire 2535ft.per ohm | $\frac{E}{I} = 0.271$ <br> $\left(\frac{E}{I}\right)^2 = 0.073441$ |
|---|---|---|---|---|
| 13.3 | 49.1 | 880 | | |
| 13.3 | 49.1 | 880 | 0.071 ohm | $R^2 = 0.00504$ |

from this:

$$l=\frac{\sqrt{0.0684}}{880}=\frac{0.2615}{880}\text{ H} \quad\text{or}\quad \frac{261{,}500{,}000}{880}=\mathbf{297{,}160\ cm.}$$

Small correction should have been made for the e.m.f. making it smaller, this would have made the agreement with the calculated value close.

**Coil wound with No. 2 wire**

Readings were:

| e.m.f. | Current | $\omega$ | Resistance will be negligible |
|---|---|---|---|
| 6.6 | 49.1 | 880 | |
| 6.6 | 49.1 | 880 | |
| 6.6 | 49.1 | 880 | |

$$l_1=\frac{E}{I\omega}=\frac{6.6}{49.1\times 880}=$$

$$=\frac{6.6}{491\times 88}\text{ H}$$

$$\text{or}=\frac{66\times 10^8}{491\times 88}\text{ cm.}$$

$$=\mathbf{152{,}750\ cm.}$$

The dimensions are as follows:

diam. core 5″=12.7 cm, length of core 38.25″=97.185 cm. Turns 91. The diam. of wire insulation is $\frac{97.185}{91}$=1.068 cm. Diam. of bare wire 0.2576″=0.6543 cm. This gives for 2 thicknesses 1.068 — 0.6543=0.4137 cm.
From this:

$$d=13.1137\text{ cm.};\qquad l'=97.185\text{ cm};\qquad N=91;\qquad N^2=8281;$$

$$S=\frac{\pi}{4}d^2=145.0644\text{ sq.cm.}\qquad l_1=\frac{4\pi}{l'}N^2S=\mathbf{155{,}330\ cm.}$$

Probably resistance is not quite negligible, but results are close enough for ordinary use of coil.

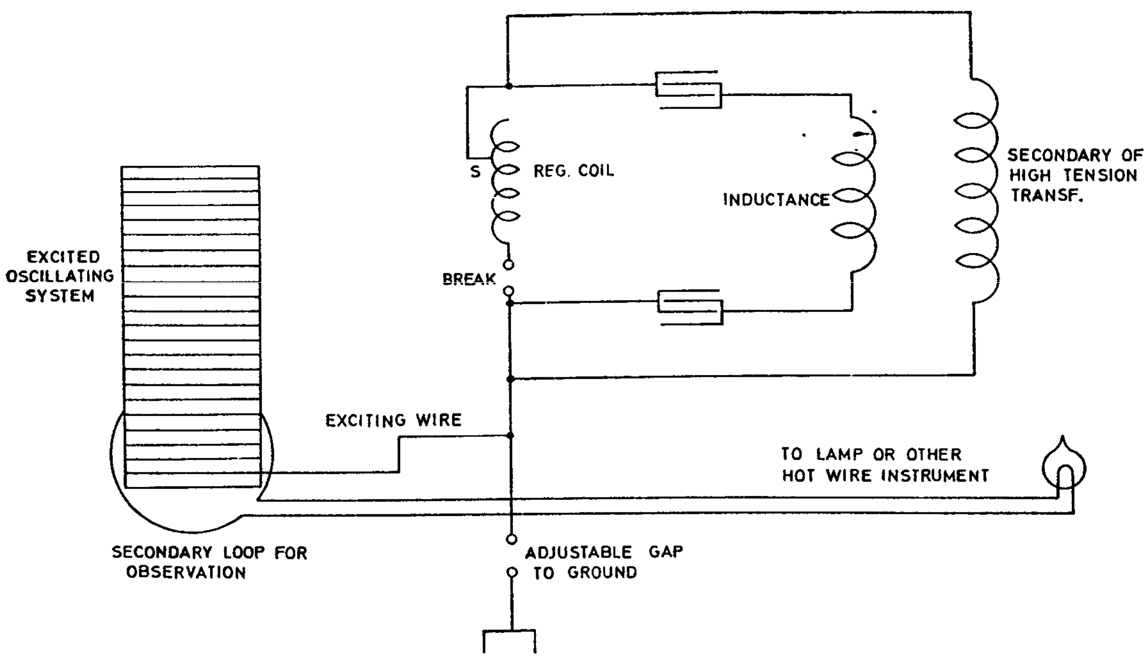
*Colorado Springs*

Nov. 10, 1899

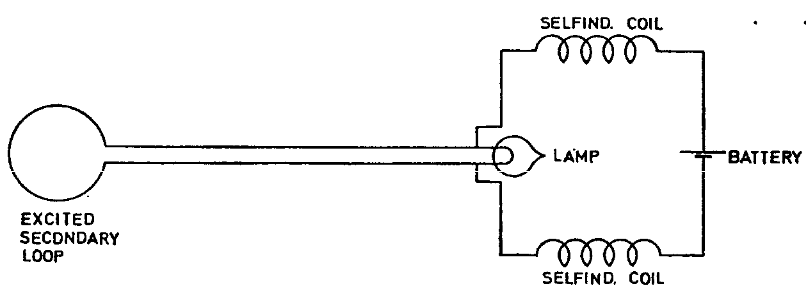
Measurements of the effective capacity of a vertical wire as modified by elevation, by resonance analysis and improved method of locating the maximum rise of e.m.f. on the excited system.

In the previous experiments on the same subject the maximum was located by observing a spark, but it was found that this mode of reading has a number of defects. One derable capacity is in the system, as it must necessarily be when investigating the modification of capacity, the tuning can never be quite sharp. When the pressures on the excited coil are large spark wires also entail considerable loss, which modifies and vitiates the results of the observations. By the spark method it is also impossible to determine the period and capacity of the excited system itself without any attachments.

In the succeeding observations a method practised in New York was resorted to. This consists of employing a small secondary circuit in feeble inductive connection with the excited system and observing in a convenient manner by a suitable instrument the changes of current or e.m.f. in the secondary. A practical and quite convenient means is to insert a minute lamp consuming but a very small fraction of the normal current and observe the degree of incandescence of the minute carbon filament or thin platinum wire. As the small secondary circuit excercises no appreciable reaction on the excited oscillating system owing to the feeble mutual induction and minute amount of energy consumed in the secondary, the method is excellent and allows close and reliable readings much more so than the spark wire method. By taking a minute lamp with an exceptionally thin and short filament the energy consumed for the readings is quite insignificant and may be less than one millionth part of the activity of the oscillating system. In the diagram below the arrangement of apparatus as used is illustrated. The excitation was again conveniently varied by an adjustable ground gap. In the secondary circuit feeding the minute lamp it was also of advantage to provide a *continuously* regulable resistance by means of which the brightness of the filament could be reduced to any degree desired. The current from the supply transformer was also regulable as this was necessary in the course of the experiments. Usually I find it advantageous to proceed as follows: first the maximum is located on the proper place of the regulating coil by altering the capacity of the primary circuit until the maximum rise takes place with the contact slide $S$ at the desired point of the regulating coil. A few



by placing the secondary circuit feeding it farther from the excited system — until the filament is barely visible when the slide $S$ is at the point giving the maximum rise on the excited system. By a little experience it becomes easy to thus locate the maximum within 1/4 of one per cent. By resorting however to ordinary experimental resources it is practicable to reach greater precision still. Of course, the greater the momentum of the excited system the better it is. There are hot wire instruments or detectors of all kinds which allow the method to be refined to any degree desired. A very simple improvement, effective and readily on hand is however to provide a source of energy for bringing the filament or wire just to a point when its luminosity can be detected by the observer. I connect the lamp to a battery of constant e.m.f. through two chocking coils graduating the turns of the latter so that the filament is brought preliminarily to the required temperature. A small amount of surplus energy supplied from the secondary loop is then sufficient to make the filament bright. Thus, less energy is taken from the excited system and the location of the maximum is rendered much more easily. The diagram below illustrates this arrangement in its simplest form. The high frequency currents can not of course pass through the chocking coils. This method is also very suitable for tuning circuits for many purposes as in telegraphy.




In the present experiments the coil before described: 1314 turns wire No. 18 on drum 14″ diam., 8 feet long was used, the object of the tests being to determine the effective capacity of the vertical wire No. 10, 50 feet long which was used in a number of cases before dwelt upon. The readings were as follows:

**Coil 1314 turns with spark wires as before used**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{46}{2}$=23 bottles=0.0207 mfd. | 16 Turns of regul. coil+connections+coil No. 6 wire |

**Note:** This reading was taken to test the spark wire method. The agreement was fairly close *15 1/2* turns being found in the previous measurements by spark analysis instead of *16* turns as now. But this was to be expected as with the *spark wires alone*, the capacity being small the tuning is very sharp. The agreement would probably not be quite so close when a large capacity is connected to the excited system.

**Coil 1314 turns alone without spark wires**

**Coil 1314 turns with vertical wire No. 10 approx. 50 feet long**

$\frac{70}{2}$=35 bottles=0.0315 mfd. 18 1/2 turns+conn.+coil No. 6 wire

The inductance of primary circuit in the first case was:

$$\left.\begin{array}{ll}\text{Coil No. 6 wire} & 284{,}000 \text{ cm} \\ 12\ 1/2 \text{ turns+conn.} & 42{,}300 \ \text{,,}\end{array}\right\} \text{total } 326{,}300 \text{ cm.}$$

In the second case it was:

$$\left.\begin{array}{ll}\text{Coil No. 6 wire} & 284{,}000 \text{ cm} \\ 18\ 1/2 \text{ turns+conn.} & 65{,}400 \ \text{,,}\end{array}\right\} \text{total } 349{,}400 \text{ cm.}$$

Calling as before $C_{s1}$ and $C_{s2}$ respectively the capacities of the excited system with and without the vertical wire we have:

$$C_{s1}=\frac{873{,}000{,}000}{10^9}=\frac{349{,}400}{10^9}\times 0.0315$$

* the inductance of excited coil from data obtained before being 87,300,000 cm.

$$C_{s1}=\frac{3494\times 0.0315}{873{,}000} \text{ mfd.}$$

Similarly from the preceeding it follows:

$$C_{s2}=\frac{3263\times 0.009}{873{,}000} \text{ mfd.}$$

This gives the capacity of the vertical wire:

$$C_{s1}-C_{s2}=\frac{3494\times 0.0315-3263\times 0.009}{873{,}000}=$$

$$=\frac{110.061-29.367}{873{,}000}=\frac{80.694}{873{,}000} \text{ mfd,}$$

or in centimeters:

$$C=C_{s1}-C_{s2}=\frac{9\times 10^5\times 80.694}{873{,}000}=\frac{72{,}624.6}{873}=\mathbf{83.2} \text{ cm.}$$

The calculated value before found was **81.5 cm.** It is assumed in the calculation that the length of the wire was 50 feet exactly, but this might not be so. It will be measured exactly when taken down. The inductance of the coil with wire No. 6 has been taken as 284,000 cm. but the measured values are higher. Taking the average of two measurements we have about 295,000 cm. This would give a higher value for the effective capacity of the vertical wire. It is also possible that the inductance of the excited coil might be a few percent different from that serving as the basis of this estimation.

It is of interest to determine from above data the capacity of the excited coil alone. The same is:

A cylinder of the dimensions of the coil excited would have a capacity $C=\dfrac{l}{2\log_e\dfrac{l}{r}}$.

Here $l=8'=243.84$ cm. $r=7''=17.78$ cm.

$$\frac{l}{r}=13.71 \qquad \log_e\frac{l}{r}=1.137037\times 2.3=2.6152$$

$$C=\frac{243.84}{2\times 2.6152}=46.6 \text{ cm.}$$

Consider now as much of the cylindrical surface as could be covered with the bare wire on the coil:

No. 18 wire diam.=0.0403″=0.1024 cm. As there are 1314 turns the wire would cover 1314×0.1024 cm=134.55 cm.

Compared with the cylinder of the length of 243.84 cm the capacity $C_1$ of the shortened would be in the proportion of 134.55 : 243.84 reduced, that is

$$C_1 \text{ would be } \frac{134.55}{243.84} \qquad C=\frac{134.55}{243.84}\times 46.6=\text{approx. } \mathbf{26\ cm.}$$

From this it would seem that a rough estimate of the capacity of such a coil might be obtained by comparison with a cylindrical surface which the bare wire would cover.

**Further experiments to ascertain the dependence of capacity npon elevation.**

In these experiments the new coil, wound with a much greater number of turns for the purpose of getting a vibration of lower frequency, was used. This coil was wound on the same drum of 14″ diam. and 8 feet length repeatedly used. It had 1314 turns of No. 18 wax covered wire. As the length of the coil and area of the coils remained exactly the same the self-induction was approximately estimated from the inductance of another coil experimented with before. The latter had 689 turns and its measured inductance was 24,000,000 cm. On this basis the inductance of the new coil was $L\left(\frac{1314}{689}\right)^2=?$, $L$ being the self-nduction of the coil referred to. This would give for $L_1=\left(\frac{1314}{689}\right)^2\times 24{,}000{,}000=3.637\times$ $\times 24{,}000{,}000=87{,}288{,}000$ cm approximately. Comparing it with another coil before described which was wound on the same drum and had 346 turns, and taking the before measured value of the inductance of the latter 6,040,000 cm we get

$$L_1=\left(\frac{1314}{346}\right)^2\times 6{,}040{,}000=14.4225\times 6{,}040{,}000=87{,}111{,}900 \text{ cm.}$$

which is very nearly the same value.

Rough readings gave:

from this: $\frac{E}{I}=80$ $\qquad$ $\left(\frac{E}{I}\right)^2=6{,}400$

$$R^2=942.5$$

$$\left(\frac{E}{I}\right)^2-R^2=5457.5$$

$R$ calculated: 4816 feet wire No.18 156.9 feet per ohm: $R=30.7$ ohm (31.68 meas.)

$$\sqrt{\left(\frac{E}{I}\right)^2-R^2}=73.88 \text{ approx.}$$

Inductance nearly **85,000,000 cm.**

For the present investigation the most probably value 87,300,000 cm will be adopted, which is still to be verified.

With the coil before described experiments were made for the purpose of once more determining the capacity of the structure of iron pipes. The adjustments were as follows:

**For coil with structure connected to free terminal:**

Capacity in primary circuit

Inductance of primary circuit 21 turns regulating coil+conn.+coil wound with wire No. 6 before described

$$\frac{(6\times 36)-2+12}{2}=113 \text{ bottles}=0.1017 \text{ mfd}$$

**For coil with the spark wires alone:**

$\frac{46}{2}=23$ bottles$=0.0207$ mfd $\qquad$ 15 1/2+conn+coil No. 6 wire.

In the first case inductance of the primary was $=359{,}000$ cm. $\left\{\begin{array}{ll}\text{Coil No. 6 wire} & 284{,}000 \text{ cm.}\\ \text{21 turns+conn.} & 75{,}000\ \text{,,}\end{array}\right\}$

In the second case $\left\{\begin{array}{ll}\text{Coil No. 6 wire} & 284{,}000 \text{ cm}\\ \text{15 1/2 turns+conn.} & 54{,}000\ \text{,,}\end{array}\right\}=338{,}000$ cm.

Calling $C_{s1}$ capacity of the excited system in first and $C_{s2}$ in the second case we have:

$$\frac{2\pi}{10^3}\sqrt{\frac{87{,}300{,}000}{10^9}C_{s1}}=\frac{2\pi}{10^3}\sqrt{\frac{359{,}000}{10^9}\times 0.1017} \text{ and}$$

$$C_{s1}=\frac{\frac{359}{10^6}\times 0.1017}{873}=\frac{359\times 0.1017}{87{,}300} \text{ mfd}$$

$$\text{or in cm } C_{s1} = \frac{9 \times 10^5 \times 359 \times 0.1017}{87,300} = \mathbf{376.4\ cm.}$$

Similarly we have: $\frac{2\pi}{10^3}\sqrt{\frac{87,300,000}{10^9}C_{s2}} = \frac{2\pi}{10^3}\sqrt{\frac{338,000}{10^9} \times 0.0207}$ and

$$C_{s2} = \frac{338,000 \times 0.0207}{87,300,000} \text{ mfd or } C_{s2} = \frac{338 \times 0.0207 \times 9 \times 10^5}{87,300} \text{ cm.}$$

$$= \frac{3042 \times 20.7}{873} = \mathbf{71.67\ cm.}$$

From this we get *effective capacity* of structure:

$$C_{s1} - C_{s2} = 376.4 - 71.67 = \mathbf{304.73\ cm,}$$

which is a value very closely before found with *extra coil.*

**Note**: The readings with spark gap as before practiced are not quite satisfactory and a new method will be tried in the next experiments.

*Colorado Springs*

Nov. 11, 1899

Experiments for the purpose of ascertaining rate of increase of capacity with elevation continued.

Again the coil with 1314 turns described before was used and the method of locating the maximum rise of potential on the excited system by means of a small circuit inductively connected to the system was resorted to. A few improvements carried out in the mode of using the induced circuit allowed closer readings than it was possible to obtain before with spark observation.

The coil was first tuned alone, without anything being attached to the free terminal. Next the vertical wire No. 10, 50 feet long (approximately) was attached to the free terminal and the tuning again effected, both the primary vibrations being carefully noted. Then a ball 30″ diam. was slipped on to the vertical wire and readings were taken in three different positions of the ball along the wire as before. The results of the observations were as follows:

**I. Coil alone**

| | |
|---|---|
| Capacity in primary or exciting circuit | Inductance in primary circuit |
| $\frac{20}{2}$ = 10 bottles = 0.009 mfd | Turns of reg. 13 coil + conn + coil |

**II. Coil with vertical wire No. 10, 50 feet approx.**

$\frac{72}{2}$=36 bottles=0.0324 mfd 17+conn.+coil No. 6 wire

**III. Coil with ball 30″ diam. vertical wire, the ball being at a height of 10′3″ from center to ground.**

$\frac{86}{2}$=43 bottles=0.0387 mfd 13 1/2+ „ + „

**IV. Coil with ball 30″ diam. and vertical wire, the ball being at a height of 34 feet from center to ground.**

$\frac{86}{2}$=43 bottles=0.0387 mfd 14 1/2+ „ + „

Note: (it seemed slightly more than 14 1/2 turns)

**V. Coil with ball 30″ diameter and vertical wire, the ball being at a height of 57′9″ from center to ground.**

$\frac{86}{2}$=43 bottles=0.0387 mfd 16 1/2+ „ + „

In the first case the inductance of primary circuit was

| | |
|---|---|
| Coil No. 6 wire | =295,000 cm |
| 13 turns+connections | = 43,300 „ |
| total | =338,300 cm. |

The primary vibration was therefore:

$$T_{p1} = \frac{2\pi}{10^3}\sqrt{0.009 \times \frac{3383}{10^7}}$$

Now calling $C_{s1}$ capacity of excited system in the first case we have:

period of excited system

$$T_{s1} = \frac{2\pi}{\ }\sqrt{C_{s1} \times \frac{85}{\ }}$$

Note: In some estimates before the inductance of this coil was calculated to be a little over 284,000 cm. and this value was taken. But two measurements made before show average of about 295,000 cm. and this value will be assumed in present estimates as being more probable until again careful measurements will be made. The results are then to be corrected.

Note: The inductance for excited coil is taken 85,000,000 cm., this being the value obtained by measurement

From this:

$$C_{s1} = \frac{0.009 \times \frac{3383}{10^7}}{\frac{85}{10^3}} = \frac{0.009 \times 3383}{85 \times 10^4} \text{ mfd, or in centimeters:}$$

$$C_{s1} = \frac{9 \times 10^5 \times 0.009 \times 3383}{85 \times 10^4} = \frac{0.81 \times 3383}{85} = \mathbf{31.84 \text{ cm.}}$$

This is slightly larger than before found owing to adoption of smaller inductance for excited coil.

In case II. the inductance of the primary circuit was:

$$\left\{ \begin{array}{ll} \text{Coil No. 6 wire as before:} & 295{,}000 \text{ cm} \\ \text{17 turns+connections} & 59{,}700 \text{ ,,} \end{array} \right\} \text{ total}=354{,}700 \text{ cm.}$$

The primary period was:

$$T_{p2} = \frac{2\pi}{10^3}\sqrt{0.0324 \times \frac{3547}{10^7}} \text{ and the secondary corresponding } T_{s2} = \frac{2\pi}{10^3}\sqrt{C_{s2} \times \frac{85}{10^3}}$$

Hence $C_{s2} = \frac{0.0324 \times 3547}{85 \times 10^4}$ mfd, or $C_{s2} = \frac{9 \times 10^5 \times 0.0324 \times 3547}{85 \times 10^4}$ cm.

$C_{s2}$=**121.68 cm.** Hence capacity of the vertical wire will be approximately

$C_{s2}$—$C_{s1}$=**89.84 cm.** This is again larger than before found but probably closer than the former value.

In case III. the primary inductance was:

$$\left\{ \begin{array}{ll} \text{Coil No. 6 wire} & 295{,}000 \\ \text{13 1/2 turns+conn.} & 46{,}200 \end{array} \right\} \text{ total } 341{,}200 \text{ cm.}$$

The primary vibration was therefore:

$$T_{p3} = \frac{2\pi}{10^3}\sqrt{0.0387 \times \frac{3412}{10^7}}$$

and the corresponding vibration of the excited system

$$T_{s3} = \frac{2\pi}{10^3}\sqrt{C_{s3} \times \frac{85}{10^3}}$$

From this we have:

$$C_{s3} = \frac{0.0387 \times \frac{3412}{10^7}}{85 \ldots} = \frac{0.0387 \times 3412}{\ldots} \text{ mfd,}$$

or

$$C_{s3} = \frac{9 \times 10^5 \times 0.0387 \times 3412}{85 \times 10^4} = 139.81 \text{ cm.}$$

The effective capacity of the ball at its lowest position (10′ 3″) from ground was therefore only $C_{s3}$—$C_{s2}$=139.81—121.68=**18.13 cm.**

Now taking cases IV. and V. the primary inductance in the

first of these cases was $\left\{\begin{array}{ll} \text{Coil No. 6 wire} & 295{,}000 \text{ cm} \\ \text{14 1/2 turns} & 50{,}100 \text{ ,,} \end{array}\right\}$

the total would be **345,100 cm.** But there is still a doubt whether there have not been 15 turns instead of 14 1/2. This is to be borne in mind. Taking for the present for the inductance 14 3/4 turns as most probable and nearer to the average value of both extreme readings in IV. and V. we have for inductance of the primary **346,000 cm.**

Now in case V. the inductance was: $\left\{\begin{array}{ll} \text{Coil No. 6} & 295{,}000 \text{ cm} \\ \text{16 1/2 turns} & 57{,}800 \text{ ,,} \end{array}\right\}$

total **352,800 cm.**

Now since in cases III, IV. and V. the capacity in the primary circuit was not varied we have:

$$C_{s3} : C_{s4} = 341{,}200 : 346{,}000 \text{ and } C_{s4} = C_{s3} \times \frac{346}{341} = \mathbf{141.78} \text{ cm.}$$

and similarly we have:

$$C_{s3} : C_{s5} = 341{,}200 : 352{,}800 \text{ and } C_{s5} = C_{s3} \times \frac{3528}{3412} = \mathbf{144.56} \text{ cm.}$$

The effective capacity of ball at its highest position was:

$$C_{s5} — C_{s2} = 144.56 — 121.68 = 22.88 \text{ cm.}$$

In the mean position the value was: $C_{s4}$—$C_{s2}$=**20.1 cm.** whereas the mean value between 22.88 and 18.13 would be **20.5 cm.** The rise is therefore *linear*. The rise in the effective capacity for 47 feet and 6″ was $\frac{18.13}{22.88 - 18.13}$ about 26.2%. Per one *hundred feet* it would be from this: 55.16% or a little over 1/2% per foot.

*Colorado Springs*

Nov. 12, 1899

Measurements of the effective capacity of the elevated structure of iron pipes were again made today in the manner described before, by means of resonance analysis, the maximum rise of potential on the excited system being determined by a minute lamp inclu-

**Coil with structure attached:**

| Capacity in primary circuit | Inductance in primary circuit turns reg. coil |
|---|---|
| $\frac{(6\times 36)+12}{2}=\frac{228}{2}=114$ | 15+conn.+coil No. 6 wire |
| bottles or 0.1026 mfd. | |

**Coil alone, without structure, only connecting wire:**

| | |
|---|---|
| $\frac{(36-6)+12}{2}=\frac{42}{2}=21$ | 7 1/2+ „ + „ |
| bottles=0.0189 mfd | |

The inductance in primary in first case was:

| | |
|---|---|
| Coil No. 6 wire | 295,000 |
| 15 turns+conn. | 52,000 |
| total | 347,000 cm. |

The inductance in primary in second case was:

| | |
|---|---|
| Coil No. 6 wire | 295,000 cm. |
| 7 1/2 turns+conn. | 23,600 „ |
| total | 318,600 cm. |

If $C_{s1}$ and $C_{s2}$ be the capacities of the excited system *with* and *without* structure, respectively, then:

$$C_{s1}=\frac{\frac{347,000}{10^9}\times 0.1026}{\frac{87,300,000}{10^9}}=\frac{3470\times 0.1026}{873,000}\text{ mfd.},$$

and similarly

$$C_{s2}=\frac{3186\times 0.0189}{873,000}$$

and

$$C_{s1}-C_{s2}=\frac{3470\times 0.1026-3186\times 0.0189}{873,000}\text{ mfd}=\frac{356.022-60.2154}{873,000}\text{ mfd},$$

or

$$\frac{9\times 10^5\times 295.8066}{873,000}=\mathbf{304.95\ cm.}$$

This is again a value close to that found with new extra coil. The agreement would be closer

*Colorado Springs*

Nov. 13, 1899

An improvement in the method of locating the maximum rises in the excited system has been effected by taking a lamp with an exceptionally thin filament, consuming only a minute fraction of an ampere, for being heated to redness enough to be perceptible, and furthermore by placing the lamp in a dark box. A "fluoroscope" was used, two holes being drilled in the sides of the box for leading the wires in. By these provisions the readings were made more exact. The new extra coil was again used for trial and the capacity of the structure of iron pipes was again determined. The readings were:

**With structure attached**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{(8 \times 36)}{2}=144$ bottles$=0.1296$ mfd | Turns+connections |
| | 18 1/2+ „ |

**Without structure** (only connecting wire)

| | |
|---|---|
| $\frac{(8 \times 36)}{2}=144$ „ $=0.1296$ mfd | 6 5/16+conn. |

**Note:** In the second case the tuning was, of course, very sharp and it was easy to locate the maximum within 1/16 of a turn of the regulating coil; in the first case, although it was naturally less sharp, it was still easy to locate within 1/4 of a turn; with great care within 1/8 of a turn. This may be said to be within 1/2% which is satisfactory, all the more as the reading is very positive.

The above results give an inductance in the primary circuit, in the first case 65,442 cm, in the second 19,578 cm, computed from the table before prepared. As the capacity in the primary remained the same in both readings we have, calling $C_{s1}$ and $C_{s2}$ capacities of the excited system *with* and without structure and $L$ inductance of the extra coil: $L=0.02$ henry

$$C_{s1}-C_{s2}=\frac{0.1296\,(65{,}442-19{,}578)\times 9\times 10^{5}}{20{,}000{,}000}\ \text{cm}=\mathbf{267.48\ cm.}$$

These readings seem most reliable so far.

*Colorado Springs*

Nov. 14, 1899

In some experiments with coil having 1314 turns wound on drum 14" diam., 8 feet long the coil was cut in the middle and the two parts, 657 turns each connected in multiple. The self-induction was then practically $\frac{1}{4}$ of the self-induction which it had used ordi-

These readings were:

e.m.f. $\begin{Bmatrix} 214 \\ 212 \\ 210 \end{Bmatrix}$ $I \begin{Bmatrix} 10.7 \\ 10.6 \\ 10.5 \end{Bmatrix}$ $\omega=880$

Average values:

| $E$ | $I$ | $\omega$ |
|---|---|---|
| 212 | 10.6 | 880 |

from this $\left(\frac{E}{I}\right)=20$, $\left(\frac{E}{I}\right)^2=400$

$R=7.9$ ohm.
$R^2=62.41$

$$\left(\frac{E}{I}\right)^2 - R^2 = 337.59 \qquad \sqrt{\left(\frac{E}{I}\right)^2 - R^2} = 18.375$$

$$L = \frac{18.375 \times 10^9}{880} \text{ cm}$$

$$=20{,}880{,}682 \text{ cm, approx.}=20{,}881{,}000 \text{ cm.}$$

The inductance of the coil as ordinarily used would then be approx.

**=83,524,000 cm.**

*Colorado Springs*

Nov. 15, 1899

Experiments with secondary of oscillator to determine capacity of structure, also capacity of secondary.

The readings were as follows:

**Secondary alone.**

Capacity in primary — Inductance in primary

$\frac{8 \times 36}{2}=144$ bottles$=0.1296$ mfd — 14 3/4 turns+connections.

**Secondary with connecting wire leading to structure.**

$\frac{8 \times 36}{2}=144$ bottles$=0.1296$ mfd — 15 1/4 „ + conn.

**Secondary with structure connected to free terminal.**

$\frac{8 \times 36}{2}=144$ bottles$=0.1296$ mfd — 19 „ + conn.

In first case inductance of primary was 51,000 cm
,, second ,, ,, 52,900 ,,
,, third ,, ,, 67,400 ,,

* All these readings and maybe previous ones to be revised.

Taking the inductance of secondary from measurements before made 9,557,000 cm. we have for $C_{s1}$, that is, capacity of secondary alone:

$$\left.\begin{aligned} T_{p1} &= \frac{2\pi}{10^3}\sqrt{\frac{51,000}{10^9}\times 0.1296} \\ T_{s1} &= \frac{2\pi}{10^3}\sqrt{\frac{9,557,000}{10^9}\times C_{s1}} \end{aligned}\right\} \quad \begin{aligned} C_{s1} &= \frac{0.1296\times 51,000}{9,557,000} = \frac{0.1296\times 51}{9557}\ \text{mfd.} \\ C_{s1} &= \frac{9\times 10^5\times 0.1296\times 51}{9557} = \mathbf{622.23\ cm.} \end{aligned}$$

Now calling $C_{s2}$ and $C_{s3}$ respectively, the capacities of the secondary system with the connecting wire and with wire and structure respectively, since the capacity in the primary was in all cases the same, we have:

$$C_{s1} : C_{s2} = 51,000 : 52,900 \text{ and } C_{s1} : C_{s3} = 51,000 : 67,400$$

and

$$C_{s2} = \frac{52,900}{51,000}\times 622.23 = \frac{529}{510}\times 622.23 = \mathbf{645,41}\ \text{cm.}$$

This gives capacity of connecting wire alone:

$$C_{s2} - C_{s1} = 645.41 - 622.23 = \mathbf{23.18\ cm.}$$

Similarly we have:

$$C_{s3} = \frac{67,400}{51,000}\ C_{s1} = \frac{674}{510}\times 622.23 = \mathbf{822.32}\ \text{cm,}$$

and from this the capacity of the structure (the effective capacity) would be:

$$C_{s3} - C_{s2} = 822.32 - 645.41 = \mathbf{176.91\ cm.}$$

But since

$$C_{s3} : C_{s2} = 67,400 : 52,900 = 674 : 529$$

we have $C_{s3}=$

$$C_{s3} = \frac{674}{529}\ C_{s2} = \frac{674}{529}\times 645.41 = \mathbf{818.54}\ \text{cm.}$$

This value checks those formerly found and shows that the readings were fairly close. The test shows however that this method of determining capacity will only give a correct

*Colorado Springs*

Nov. 16, 1899

*Experiments continued on the influence of elevation upon capacity of system connected to earth.*

A new coil wound on drum 14" diam., 8 feet long was used. It had 344 turns No. 10 wire. From the fact that another coil with 346 turns had an inductance of a little over 6,000,000 cm. it is not far away to take the inductance of this coil at that figure.

In the experiments presently described a length of wire No. 12 was used (15 meters long.) The object was to ascertain the capacity of the wire used in connection with the coil. The results of the readings were as follows:

**Coil alone without vertical wire.**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{36}{2}=18$ bottles$=0.0162$ mfd | $4\frac{13}{16}$ turns+connections. |

**Coil with vertical wire No. 12, 15 meters long.**

| | |
|---|---|
| $\frac{36}{2}=18$ bottles$=0.0162$ mfd | 14 3/4 turns+conn. |

The inductance in primary in the first case was 14,530 cm. In second case 51,000 cm, approx.

If $C_{s1}$ and $C_{s2}$ be again the capacity of the excited system in the first and second case respectively, we have by analogy from previous experiments:

$$C_{s1}=\frac{\frac{14,530}{10^9}\times 0.0162}{\frac{6,000,000}{10^9}}=\frac{14,530\times 0.0162}{6\times 10^6}\ \text{mfd}$$

or

$$C_{s1}=\frac{9\times 14,530\times 0.0162\times 10^5}{6\times 10^6}=\mathbf{35.3\ cm.}$$

Since the capacity in the primary circuit remained the same in both experiments, we have:

$$C_{s1}:C_{s2}=14,530:51,000 \text{ and } C_{s2}=\frac{5100}{1453}\ C_{s1}=\frac{5100}{1453}\times 35.3=\mathbf{121.15\ cm.}$$

Hence the capacity of wire alone

This is the actual or effective capacity of the wire as used with the coil. But the calculated capacity would be

$$C = \frac{l}{2 \log_e \frac{l}{r}}$$

Here $l=15$ meters=1500 cm. $\frac{l}{r} = 7308$

$r=0.08081''=0.20526$ cm.

$$\log_e \frac{l}{r} = 3.863799 \times 2.3 = 8.887$$

$$C = \frac{1500}{2 \times 8.887} = \frac{1500}{17.774} = \mathbf{84.4 \ cm.}$$

According to this estimate the effective capacity would be only about 1.7% larger than the calculated capacity.

*Colorado Springs*

Nov. 17, 1899

Experiments to ascertain capacity of various lengths of vertical wire.

Coil with 344 turns and No. 10 on drum 14" diam., 8 feet long was used. The wire to be tested was No. 12 of a length of 15 meters. The full length was first connected to the free terminal of the coil excited as usual and then 3 meters were cut off each time and the adjustment of the primary circuit made. The results are indicated below:

| Capacity in primary circuit | Length of vertical wire | Inductance in pr. cir. |
|---|---|---|
| $\frac{22}{2}=11$ bottles=0.0099 mfd | 15 meters | 21 1/2 turns+conn. |
| ,, ,, | 12 ,, | 19 ,, + ,, |
| ,, ,, | 9 ,, | 16 1/4 ,, + ,,<br>17 |
| ,, ,, | 6 ,, | 13 3/4 ,, + ,,<br>13 5/8 ,, + ,, |
| ,, ,, | 3 ,, | 10 1/2 ,, + ,, |

*Approximate estimates from the above readings:*

The inductance of coil 344 turns is assumed to be $6 \times 10^6$ cm. which is still to be confirmed by close measurement. The inductance of primary when no wire was attached was 7 3/8 turns + conn. = 23,157 cm. With 3 meters wire attached it was 10 1/2 + conn. = = 34,642 cm. Hence calling $C_{s1}$ and $C_{s2}$ the capacities of the excited system, in the two cases respectively we have:

$$T_{p1} = \frac{2\pi}{10^3}\sqrt{0.0099 \times \frac{23157}{10^9}} \qquad C_{s1} = \frac{0.0099 \times 23{,}157}{6 \times 10^6} \text{ mfd, or in centimeters:}$$

$$T_{s1} = \frac{2\pi}{10^3}\sqrt{\frac{6 \times 10^6}{10^9} C_{s1}} \qquad C_{s1} = \frac{9 \times 0.0099 \times 23{,}157}{60} = \mathbf{34.386} \text{ cm}$$

$$T_{p2} = \frac{2\pi}{10^3}\sqrt{0.0099 \times \frac{34{,}642}{10^9}}$$

and since the capacity in the primary circuit was the same in both cases:

$$T_{s2} = \frac{2\pi}{10^3}\sqrt{\frac{6 \times 10^6}{10^9} C_{s2}} \qquad C_{s2} = \frac{34{,}642}{23{,}157} C_{s1} = \frac{34{,}642}{23{,}157} \times 34.386 = \mathbf{51.44} \text{ cm.}$$

The value of effective capacity of the first 3 meters of wire was therefore $C_{s2} — C_{s1} =$ $= 51{,}44 — 34{,}386 = \mathbf{17.054}$ **cm.**

Calling now $C_{s3}$ the capacity of the excited system when 6 meters of wire connected to it we have, since in this case the inductance of the primary was 13 3/4 turns + conn. = = 47,154 cm.

$$C_{s3} = \frac{47{,}154}{23{,}157} C_{s1} = \frac{47{,}154}{23{,}157} \times 34.386 = \mathbf{70.02 \text{ cm.}}$$

Hence the value of effective capacity of the second piece of wire 3 meters long was

$$C_{s3} — C_{s2} = 70.02 — 51.44 = \mathbf{18.58 \text{ cm.}}$$

Now in the case when 9 meters of wire were attached the inductance of the primary was 16 1/4 turns + conn. = 56,779 cm. Calling $C_{s4}$ the corresponding capacity of the excited system we have:

$$C_{s4} = \frac{56{,}779}{23{,}157} \times 34.386 = 84.307 \text{ cm.}$$

Hence effective value of the 3rd piece of 3 meters length was

$$C_{s4} — C_{s3} = 84.307 — 70.02 = 14.287 \text{ cm.}$$

$C_{s4}=\frac{59,665}{23,157}\times 34.386=$ **88.597 cm.** According to this the effective value of the $3^{rd}$ piece 3 meters long would then be

$$C_{s4}—C_{s3}=88.597—70.02=\mathbf{18.577}\ \text{cm.}$$

When 12 meters wire were attached the inductance of primary was found to be 19 turns+conn.=67,367 cm. Hence similarly $C_{s5}=\frac{67,367}{23,157}\times 34.386=106.034$ cm, and from this the value of $4^{th}$ piece of wire
$C_{s5}—C_{s4}=100.034—84.307=$ **15.727 cm.** But according to second reading it would be:

$$100.034—88.397=\mathbf{11.437}\ \textit{cm}, \text{ only.}$$

Finally, when 15 meters were attached the inductance in primary was: 21 1/2 turns+ +conn.=73,142 cm, and therefore: $C_{s6}=\frac{73,142}{23,157}\times 34.386=108.609$ cm. and this would give as value of the last piece of three meters

$$C_{s6}—C_{s5}=108.609—100.034=\mathbf{8.575}\ \text{cm only.}$$

Here possibly inductance of wire begins to assert itself. These values as found are still to be considered.

*Colorado Springs*

Nov. 18, 1899

Experiments were continued to ascertain influence of elevation upon capacity of a system connected to earth as in previous instances. Coil 344 turns referred to before was again used. Also wire vertical No. 10, 50 feet length and ball 30″ diam. The procedure was as in a similar case before. The results were as follows:

**Coil without vertical wire.**

| Capacity in primary | Inductance in primary |
|---|---|
| $\frac{36}{2}=18$ bottles=0.0162 mfd | $4\frac{13}{16}$ turns+conn. |

**Coil with vertical wire No. 10, 50 feet.**

| | |
|---|---|
| $\frac{36}{2}=18$ bottles=0.0162 mfd | 14 3/4 turns+conn. |

**Coil with ball 30″ diam. slid on vertical wire.**

| Capacity primary | Height of ball from center to ground | Inductance in primary |
|---|---|---|
| $\frac{36}{2}$=18 bottles=0.0162 mfd. | 10′ 1″ | 16 1/4 turns+conn. |
| ,, ,, | 33′ 8″ | 16 7/16 ,, +conn. |
| ,, ,, | 57′ 3″ | 16 5/8 ,, +conn. |

On the basis of these readings the following results are obtained: In the first experiment when the wire was attached, the inductance in primary was: $4\frac{13}{16}$ turns+conn.= =14,526 cm. Calling again $C_{s1}$ capacity of excited system we have

$$C_{s1} = \frac{0.0162 \times \frac{14,526}{10^9}}{\frac{6 \times 10^6}{10^9}} \text{ mfd}$$

$$C_{s1} = \frac{0.0162 \times 14,526 \times 9 \times 10^5}{6 \times 10^6} = \mathbf{35,298 \ cm.}$$

In the second case with wire 50 long attached to the excited system the capacity of primary being the same as before and the inductance of primary being 14 3/4 turns+ +conn=51,004 cm, we have:

$$C_{s2} = \frac{51,004}{14,526} C_{s1} = \frac{51,004}{14,526} \times 35.298 = 3.511 \times 35.298 = 123.931 \text{ cm.}$$

Hence capacity of wire

$$C_{s2} - C_{s1} = 123.93 - 35.298 = \mathbf{88.632 \ cm.}$$

Now with ball at its lowest position capacity in primary was as before and inductance 16 1/4 turns+conn.=56,779 cm. Hence

$$C_{s3} = \frac{56,779}{14,526} C_{s1} = 3.9088 \times 35.298 = \mathbf{137.973 \ cm.}$$

From this effective value of ball at the height of 10′1″ was

$$C_{s3} - C_{s2} = 137.973 - 123.931 = \mathbf{14.042 \ cm.}$$

With ball at a height of 33′8″ the inductance in primary was 57,502 cm. and at the height of 57′3″ it was 58,223 cm. As the capacity in primary was the same the values for $C_{s4}$ and $C_{s5}$, respectively, are at once found since

$$C_{s4} = \frac{57,502}{56,779} C_{s3} \quad \text{and} \quad C_{s5} = \frac{58,223}{56,779} C_{s3}$$

From this we find

The effective value of capacity of ball at the height

of 33′ 8″ was $C_{s4}-C_{s2}=139.725-123.931=\mathbf{15.794}$ **cm**, and

at the height of 57′ 3″ $C_{s5}-C_{s2}=141.482-123.931=\mathbf{17.551}$ **cm.**

From these results it would appear that from the lowest to the highest position there was an increase of about 25% total or per foot of elevation 0.53%. These readings were made under conditions not the best.

*Colorado Springs*

Nov. 19, 1899

In order to further investigate effect of elevation upon the capacity of a system as before a cylinder of thin sheet iron 4″ in diam. was prepared in sections 2 meter long each, there being 7 sections in all. The separate tubes were slipped one into the other so that when one was taken off each time the total length was shortened by exactly two meters. The cylinder was supported vertically above the coil used in the experiments by means of a cord extending from the wooden structure in previous instances described and the experiments were usually begun with the full length of tube and after each adjustment one length was taken off. The results were as follows:

| Capacity in primary circuit | Inductance in primary | Length of cylinder |
|---|---|---|
| $\frac{2\times 36}{2}=36$ bottles=0.0324 mfd | 10 3/4 turns+conn. | 14 meters |
| „ „ „ | 9 7/8 „ + „ | 12 „ |
| „ „ „ | 8 3/4+1/16 „ + „ | 10 „ |
| „ „ „ | 7 13/16 „ + „ | 8 „ |
| „ „ „ | 6 11/16 „ + „ | 6 „ |
| „ „ „ | 5 5/16 „ + „ | 4 „ |
| „ „ „ | 3 3/4 less 1/32 + „ | 2 „ |
| „ „ „ | 1 3/8+1/16 „ + „ | 0 „ |

These results are to be calculated.

**Note:** coil used 344 turns drum 14″ diam. 8 feet length.

*Colorado Springs*

Nov. 20, 1899

Experiments with coil 344 turns to determine influence of elevation upon capacity

### Coil alone

| Capacity in primary | Inductance in primary |
|---|---|
| $\frac{2 \times 36}{2}$=36 bottles=0.0324 mfd | 1 3/8 turns+conn. |

### Coil with vertical wire 50 feet (No. 10)

| | |
|---|---|
| $\frac{2 \times 36}{2}$=36 bottles=0.0324 mfd | 8 1/16 turns+conn. |

### Experiments with ball 30″ diam.

| Capacity primary circuit | Height of ball from center to ground | Inductance primary |
|---|---|---|
| $\frac{2 \times 36}{2}$=36 bottles=0.0324 mfd | 10′ 1″ | 8 7/8+conn. |
| ″ ″ ″ | 33′ 8″ | 9 +conn. |
| ″ ″ ″ | 57′ 3″ | 9 1/8+conn. |

from this follows:

When coil was alone the inductance of primary was 1 3/8 turns +conn.=7121 cm. Hence, taking inductance of coil=$6 \times 10^6$ cm, we have similarly to preceding

$$C_{s1} = \frac{0.0324 \times 7121}{6 \times 10^6} \text{ mfd} \quad \text{or} \quad C_{s1} = \frac{9 \times 10^5 \times 0.0324 \times 7121}{6 \times 10^6} =$$

=**34.61 cm**, slightly less than found before.

Now in second experiment with wire connected to vibrating system the inductance was 8 1/16 turns+conn.=25,472 cm. Since the capacity was the same we have as before

$$C_{s2} = \frac{25{,}472}{7121} C_{s1} = 3.577 \times 34.61 = \mathbf{123.7999\ cm.}$$

From this follows for capacity of wire alone

$$C_{s2} - C_{s1} = 123.7999 - 34.61 = \mathbf{89.19\ cm.}$$

When ball was at a height of 10′1″ the inductance was 8 7/8 turns+conn.=28,389 cm; in the middle position it was 9 turns+conn.=28,870 cm, and in the highest position it was 9+1/8 turns+conn.=29,351 cm. From this following values are obtained:

$$C_{s4}=\frac{28{,}870}{7121}C_{s1}=4.054\times 34.61=\mathbf{140.301\ cm.}\ \text{and}$$

$$C_{s5}=\frac{29{,}351}{7121}C_{s1}=4.1218\times 34.61=\mathbf{142.6555\ cm.}$$

The effective capacity of ball at lowest position was

$$C_{s3}—C_{s2}=137.9783—123.7999=14.1784\ \text{cm.}$$

At the middle position it was

$$C_{s4}—C_{s2}=140.301—123.7999=16.5011\ \text{cm.}$$

and at the highest

$$C_{s5}—C_{s2}=142.6555—123.7999=18.8556\ \text{cm.}$$

Hence from lowest to highest there was an increase of about 33% or very nearly an increase of 0.7% per foot or 70% per 100 feet.

*Colorado Springs*

Nov. 21, 1899

Investigation on influence of elevation upon the capacity continued: The same coil 344 turns on drum of 14″ diam., 8 feet long was used. The object was to ascertain the relative capacities of a wire in vertical and horizontal position. A wire No. 14, 10 meters long was experimented with. Results were as follows:

**Coil with wire vertical, lowest point being 8′ 8″ from ground.**

| Capacity in primary circuit | Inductance in primary |
|---|---|
| $\frac{22}{2}=11$ bottles=0.0099 mfd | 17 1/2 turns+conn. |

**Coil with same wire horizontal at distance of 8′ 8″ from ground.**

| | |
|---|---|
| $\frac{22}{2}=11$ bottles=0.0099 mfd | 18 turns+conn. |

The capacity in exciting circuit was now changed and readings again taken, the

**Coil with above wire vertical as before**

$2 \times \frac{36}{2} = 36$ bottles $= 0.0324$ mfd 6 5/8 turns+conn.

**Coil with same wire horizontal as before**

$2 \times \frac{36}{2} = 36$ bottles $= 0.0324$ mfd 6 3/4 turns+conn.

Determination of the values of the capacities from preceeding readings:

**First set of readings: With wire vertical** the inductance in primary circuit was 17 1/2 turns+ +conn.=61,592 cm, and with wire horizontal it was 18 turns+conn.=63,517 cm. Since in all cases before the capacity of the coil alone was found to be approximately 35 cm$=C_{s_1}$ the capacity of the wire in the vertical and horizontal positions was as follows:

*Wire in horizontal position:*

$$C_{s2} = \frac{0.0099 \times 63{,}517}{6 \times 10^6} \text{ mfd or } C_{s2} = \frac{0.0891 \times 63{,}517}{60} \text{ cm} = \mathbf{94.32\ cm.}$$

and this gives for capacity of wire in horizontal position:

$$C_{s2} - C_{s1} = 94.32 - 35.00 = \mathbf{59.32\ cm.}$$

Wire in vertical position $C'_{s2} = \frac{0.0099 \times 61{,}592}{6 \times 10^6}$ mfd or $\frac{0.0891 \times 61{,}592}{60}$ cm$=91.464$ cm, and this gives capacity of wire in vertical position:

$$C'_{s2} - C_{s1} = 91.464 - 35.00 = \mathbf{56.464\ cm} \text{ or a little less.}$$

**From second set of readings we get:**

**Wire vertical:** Inductance in primary was 6 5/8 turns+conn.=20,631 cm. Hence

$$C''_{s2} = \frac{0.0324 \times 20{,}631}{6 \times 10^6} \text{ mfd or } \frac{0.2916 \times 20{,}631}{60} \text{ cm} = 100.26 \text{ cm}$$

and hence value of capacity in this case was for wire alone

$$C''_{s2} - C_{s1} = 100.26 - 35 = \mathbf{65.26\ cm.}$$

**Wire horizontal:** Inductance in primary was 6 3/4 turns+conn.=21,052 cm. Hence

$$'' \quad 0.0324 \times 21{,}052 \qquad 0.2916 \times 21{,}052$$

and the capacity of the wire in horizontal position was then:

$$C''_{s2} - C_{s1} = 102.31 - 35.000 = \mathbf{67.31}\ \textbf{cm.}$$

These readings do not agree as well as they ought to.

**To be gone over.**

*Colorado Springs*

Nov. 22, 1899

Measurement of small capacities by resonance method.

This method is suitable to determine capacities too small to be measured in other ways conveniently. Coil with 344 turns before described was again used.
**Results:**

**Coil alone with short piece of stout wire connected to the free terminal.**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{2 \times 36}{2} = 36$ bottles $= 0.0324$ mfd | $1\ 1/2$ turns + connections |

**Coil with incandescent lamp 16 c.p. 100 V with two filaments attached to short thick wire**

| | |
|---|---|
| $\frac{2 \times 36}{2} = 36$ bottles $= 0.0324$ mfd | $1\frac{19}{32}$ turns + conn. |

This test gave an idea of the capacity (effective) of the lamp. The primary inductance in first case was 7314 cm. and in the second 7458 cm. from table prepared. From this follows:

$$C_{s1} = \frac{0.0324 \times 7314}{6 \times 10^6}\ \text{mfd or } C_{s1} = \frac{0.2916 \times 7314}{60}\ \text{cm} = \mathbf{35.546}\ \textbf{cm.}$$

$$C_{s2} = \frac{0.0324 \times 7458}{6 \times 10^6}\ \text{mfd or } C_{s2} = \frac{0.2916 \times 7458}{6 \times 10^6}\ \text{cm} = \mathbf{36.246}\ \textbf{cm.}$$

Here $C_{s1}$ and $C_{s2}$ were respectively the capacities of the system without lamp and with lamp attached. Hence the actual or effective capacity of the lamp in this system was

An approximate idea is also obtained of the capacity of the short piece of stout wire used to attach the small bodies the capacity of which was to be determined. Namely the capacity of the excited system alone being before determined about 35 cm, the capacity of the wire would be

$$35.546-35.000=\mathbf{0.546\ cm.}$$

*Colorado Springs*

Nov. 23, 1899

Measurement of small capacities by resonance method and mode of determining maximum rise before described by means of diminutive circuit was continued. The coil with 344 turns was again used and in order to get better readings on the self-induction regulating coil in the primary, the primary capacity was reduced. The results were:

1.

**Coil with short stout wire alone as before.**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{36}{2}=18$ bottles$=0.0162$ mfd | $4\frac{13}{16}$ turns+conn. |

2.

**Coil with lamp same as before.**

| | |
|---|---|
| $\frac{36}{2}=18$ bottles$=0.0162$ mfd | $4\frac{15}{16}$ turns+conn. |

3.

**Coil with same lamp seal broken**

| | |
|---|---|
| $\frac{36}{2}=18$ bottles$=0.0162$ mfd | $4\frac{31}{32}$ turns+conn. |

**Note:** Curious, the increased capacity probably due to absorption.

4.

**Coil with one of my Roentgen tubes as described in articles E.R.**

$\frac{36}{2}=18$ bottles=0.0162 mfd — 5 1/8 turns+conn.

5.

**Coil with "double focus tube" target connected.**

$\frac{36}{2}=18$ bottles=0.0162 mfd — 5 1/16 turns+conn.

6.

**Coil with same tube one of the electrodes connected.**

$\frac{36}{2}=18$ bottles=0.0162 mfd — 5 3/32 turns+conn.

* **Note:** all of these tubes developed rays fairly strong while tested.

7.

**Coil with Lennard tube single terminal as described by me E.R., poorly exhausted, streamers passing through it.**

$\frac{36}{2}=18$ bottles=0.0162 mfd — 5 turns+conn.

From these measurements the capacities can now be found.

Calling the inductances in the primary circuit in each succeeding experiment respectively $L_1$, $L_2$, $L_3$, $L_4$, $L_5$, $L_6$ and $L_7$ we have with reference to prepared table:

$L_1=4$ 13/16 turns+conn.=14,526 cm.
$L_2=4$ 15/16 „ +conn.=14,947 „
$L_3=4$ 31/32 „ +conn.=15,053 „
$L_4=5$ 1/8 „ +conn.=15,579 „
$L_5=5$ 1/16 „ +conn.=15,368 „
$L_6=5$ 3/32 „ +conn.=15,473 „

Calling furthermore the corresponding capacities of the excited system
$C_{s1} \dots C_{s7}$
all of them can be at once determined from $C_{s1}$ since
$C_{s2}=\frac{L_2}{-}C_{s1}$

Now analogous to previous preceedings of this kind

$$C_{s1}=\frac{0.0162\times L_1}{6\times 10^6}\text{ mfd. or }C_{s1}=\frac{0.0162\times 14{,}526\times 9\times 10^5}{6\times 10^6}=\mathbf{35.298\ cm.}$$

Taking approximately $C_{s1}=\mathbf{35.3\ cm}$ we have:

$$\left.\begin{aligned}
C_{s2}&=\frac{L_2}{L_1}C_{s1}=\frac{14{,}947}{14{,}526}C_{s1}=1.029\times 35.3=36.324\text{ cm}\\
C_{s3}&=\frac{L_3}{L_1}C_{s1}=\frac{15{,}053}{14{,}526}C_{s1}=1.0363\times 35.3=36.58\text{ cm}\\
C_{s4}&=\frac{L_4}{L_1}C_{s1}=\frac{15{,}579}{14{,}526}C_{s1}=1.0725\times 35.3=37.859\text{ cm}\\
C_{s5}&=\frac{L_5}{L_1}C_{s1}=\frac{15{,}368}{14{,}526}C_{s1}=1.058\times 35.3=37.347\text{ cm}\\
C_{s6}&=\frac{L_6}{L_1}C_{s1}=\frac{15{,}473}{14{,}526}C_{s1}=1.0652\times 35.3=37.6\text{ cm}\\
C_{s7}&=\frac{L_7}{L_1}C_{s1}=\frac{15{,}158}{14{,}526}C_{s1}=1.0435\times 35.3=36.8355\text{ cm}
\end{aligned}\right\}\text{ from these values follow:}$$

| | |
|---|---|
| Capacity effective of lamp experiment | $2=C_{s2}-C_{s1}=36.324-35.3=\mathbf{1.024\ cm.}$ |
| ,, ,, seal broken | $3=C_{s3}-C_{s1}=36.58-35.3=\mathbf{1.28\ cm.}$ |
| ,, of my Roentgen tube exp. | $4=C_{s4}-C_{s1}=37.859-35.3=\mathbf{2.559\ cm.}$ |
| ,, double focus tube target connected | $5=C_{s5}-C_{s1}=37.347-35.3=\mathbf{2.047\ cm.}$ |
| ,, ,, ,, electrode connected | $6=C_{s6}-C_{s1}=37.6-35.3=\mathbf{2.3\ cm.}$ |
| ,, ,, Lennard tube described | $7=C_{s7}-C_{s1}=36.8355-35.3=\mathbf{1.5355\ cm.}$ |

*Colorado Springs*

Nov. 24, 1899

A test was made with the object of ascertaining how close the table of inductances prepared from measured data agreed with the values determined by resonance method. The procedure was as follows: the coil with 344 turns on drum 14" diam., 8 feet long was again used as suitable for the test and it was excited in the manner before described. In order to establish a different relation between capacity and self-induction of the period of the system remained in each case the same the products of the capacity and self-inductance in primary remained constant also. Now the capacities in the primary in the succeeding experiments being known or exactly measurable, the various values of inductance in primary were obtained from the relation:

$$L_1\, C_1 = L_2\, C_2 = L_3\, C_3 = \text{etc.}$$

The period of the secondary system was $T_s = \dfrac{2\pi}{10^3}\sqrt{LC_{s1}}$.

The inductance of coil 344 turns being about $6 \times 10^6$ cm. and the average value for $C_{s1}$ from a number of readings with different values of inductance and capacity in primary circuit being 34.9 cm., the period of secondary or excited circuit was thus given.

A reading was now taken at random and resonance was obtained with constants in primary circuit as follows:

| Capacity in primary circuit | Inductance in primary |
|---|---|
| $\dfrac{36}{2} = 18$ bottles $= 0.0162$ mfd | $4\dfrac{13}{16}$ turns+conn. |

from this the period of primary circuit was:

$T_p = \dfrac{2\pi}{10^3}\sqrt{0.0162 \times L}$ $L$ being the inductance in primary

Now $T_p = T_s$ or $0.0162 \times \dfrac{L}{10^9} = \dfrac{6 \times 10^6}{10^9} \times \dfrac{34.9}{9 \times 10^5}$ and from this we get $L$ in centimeters:

$$L = \frac{6 \times 10^6 \times 34.9}{9 \times 10^5 \times 0.0162} = \frac{34.9 \times 6}{9 \times 0.0162} = \frac{698}{0.0486} = L = \mathbf{14{,}362\ cm.}$$

by resonance method.

Now from table prepared:

$$\text{Inductance } L = 4\frac{13}{16} + \text{conn.} = \left\{\begin{array}{ll} \text{Inductance } 4\ 1/2 \text{ turns+conn.} & = 13{,}474 \text{ cm.} \\ \text{Inductance } 5 \text{ turns+conn.} & = 15{,}158 \text{ cm.} \\ \hline \text{Ind. of } 1/2 \text{ turns} & = 1684 \text{ cm.} \\ \text{Ind. of } 1/16 \text{ turns} & = 210.5 \text{ cm.} \end{array}\right.$$

Ind. of 5/16 turn$=5 \times 210.5 = 1052$ cm approx.

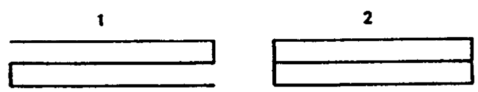
Consequently inductance $L = \text{Ind.}\left\{\begin{array}{c} 4\ 1/2 + 5/16 \text{ turn} \\ +\text{conn.} \end{array}\right\} = 4\dfrac{13}{16}$ turn+conn.$=$

$13{,}474 + 1052 = \mathbf{14{,}526\ cm}$

*Colorado Springs*

Nov. 25, 1899

Experiment which follows was made to ascertain how the capacity of the same conductor may be altered by different distribution. The experiment was performed in the following manner. Two lengths of wire No. 10 were taken (rubber covered) and one length was bent zigzag fashion so that a piece with three parallel wires was obtained one meter long. The other length was cut in three pieces 1 meter long each and these were connected at the ends. The difference between the two pieces so prepared will appear



from the sketch in which 1. shows the zigzag wire and 2. the wire cut in three pieces joined in multiple. The distribution in both cases was radically different. These pieces were one after the other placed on the free terminal of a coil with 344 turns and in each case the primary adjusted until resonance was observed. The wires were placed vertically, in the prolongation of the axis of the coil.

An experiment was furthermore made in tuning, not to the real vibration but to a higher harmonic (the next octave) of the primary. The results (with spark gaps slightly changed) were:

| Capacity in primary circuit | Inductance primary |
|---|---|
| $\frac{36}{2}=18=0.0162$ mfd **with wires multiple** | 1 1/8 turns+conn. |
| $\frac{36}{2}=18=0.0162$ mfd **with wire zigzag** | 1 1/16 turns+conn. |

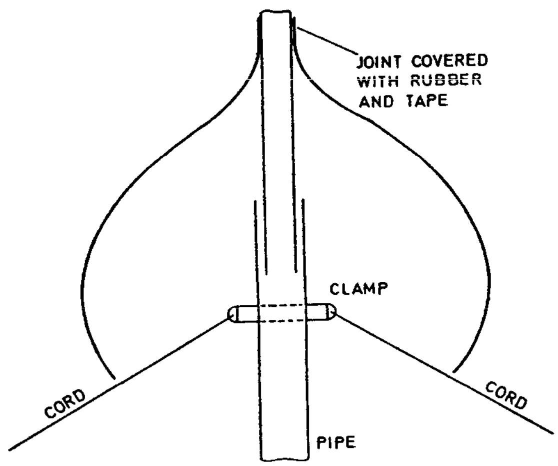
Now the primary inductance in the first case was 6736 cm and in the second case 6635 cm. Hence, the inductance remaining practically the same, the capacity (effective) of the zigzag wire was smaller to the extent of nearly **1.6%**.

*Colorado Springs*

Nov. 26, 1899

Determination of the capacity of structure of iron pipes by improved method before described.

**Note:** Originally the structure, to prevent lateral play, was supported sideways by 8 projecting beams at a height of about 80 feet, each beam having fastened into its end a strong champagne bottle. The necks of the bottles abutted against the iron pole it did not allow going beyond a certain pressure as the sparks from the iron pipes would jump to the beams which had the bottles fastened into them. To overcome this defect a plan was adopted, contrived long ago, which consisted in providing a conical roof or hood (made in two parts) rounded on the periphery to reduce loss by leakage and fastening four cords under the roof for the purpose of preventing lateral play and steadying this pole. This arrangement is excellent as the sparks can not jump upon and follow the cords to the ground being fastened under the roof where the electrical pressure was extremely




small. The arrangement is indicated in the sketch. The dimensions of the hood were: outside diam. 8 feet., diam. of small circle on periphery 9". The height of the conical surface about 3 1/2 feet. The cords were led to the four corners of the building and fastened to the same by means of a cable of sheet wires over which was slipped a rubber hose with very thick wall and which was wrapped around three glass insulaters supported on the pole on each corner. It was thought of advantage to insulate the ropes thoroughly and for this purpose they were soaked about a week in linseed oil boiled out and dried in the sun afterward. The cords went down at an angle such that the nearest point of the hood was two feet distant. This arrangement permitted the charging of the pole easily up to a million volts. This is the best arrangement I have found so far for supporting a body to be charged to so high a potential as is necessary for instance in the transmission of messages over great distances. It has been in use since a few weeks ago but the measurements of capacity of the structure before recorded were made without the hood. Presently the readings were taken with the hood with following results:

**Coil 344 turns drum 14" with iron structure connected to free terminal.**

| Capacity in primary circuit | Inductance in primary circuit |
|---|---|
| $\frac{2\times 36+12}{2}=\frac{84}{2}=42$ bottles $=0.0378$ mfd | 21 1/8 turns+conn. |

**Coil with connecting wire alone shifted away from structure (4 feet).**

From this follows: the inductance in primary circuit in the first case was 75,548 cm, in the second case 12,319 cm referring to table of inductances before used. Hence capacity of excited system in first

$$C_{s1} = \frac{0.0378 \times 75{,}548}{6 \times 10^6} \text{ mfd, or } \frac{0.3402 \times 75{,}548}{60} \text{ cm} = C_{s1}$$

And similarly $C_{s2} = \dfrac{0.3402 \times 12{,}319}{60}$ cm, $C_{s2}$ being capacity of excited system in second experiment. This gives for actual or effective capacity of **structure with hood**

$$C_{s1} - C_{s2} = \frac{0.3402}{60}(75{,}548 - 12{,}319) \text{ cm} = \frac{0.3402}{60} \times 63{,}229 \text{ cm} = \mathbf{358.5 \text{ cm.}}$$

* Small corrections for inductance may have to be taken later.

Effective capacity of structure of iron pipes with new hood again determined by resonance method. The new "extra coil" was used, its inductance being as before 0.02 H. The readings were as follows:

| Capacity in primary | Inductance in primary |
|---|---|
| **Coil with structure** and connecting wire | |
| 5×36—12=168 bottles=0.1512 mfd | 20 3/8 turns+conn. |
| **Coil with connecting wire alone** placed at 4 ft. distance | |
| 4×36=144 bottles=0.1296 mfd | 7 turns+conn. |
| other readings: | |
| 50 bottles=0.045 mfd | 17 1/4 turns+conn |
| 40 „ =0.036 mfd | 20 turns+conn. |
| 38 „ =0.0342 mfd | 20 3/4 turns+conn. |
| 39 „ =0.0351 mfd | (approx) 20 3/8 turns+conn. |

From these readings follows:

Inductance in first case, with structure, in primary was 20 3/8 turn+conn.=72,661 cm.
Inductance in second case, without structure, in primary was 7 turn+conn.=21,894 cm.

Calling $C_{s1}$ and $C_{s2}$ the effective capacities of the excited system in the two cases respectively, we have:

$$C_{s1} = \frac{0.1512 \times 72{,}661}{2 \times 10^7} \text{ mfd, and } C_{s2} = \frac{0.1296 \times 21{,}894}{2 \times 10^7} \text{ mfd, hence}$$

$$C_{s1} - C_{s2} = \frac{0.1512 \times 72{,}661 - 0.1296 \times 21{,}894}{2 \times 10^7} =$$

$$= \frac{10{,}986.3432 - 2837.4624}{2 \times 10^7} = \frac{8148.8808}{2 \times 10^7} \text{ mfd,}$$

or

$$\frac{9 \times 8148.8808}{2 \times 10^2} \text{ cm} = \mathbf{366.7 \text{ cm.}}$$

Capacity of structure without hood before found with extra coil was 311.2 cm, hence for hood alone we get 366.7—311.2=**55.5 cm.** From first and last reading it appears that the secondary capacities in the two cases were as $\frac{168}{39}$. Now the capacity of excited system in last reading was

$$C'_{s2} = \frac{0.0351 \times 72{,}661}{2 \times 10^7} \text{ mfd, or } C'_{s2} = 144.77 \text{ cm.}$$

From this would follow value

$$C'_{s1} = \frac{168}{39} \times 114.77 = 494.39 \text{ cm.}$$

Hence $$C'_{s1} - C'_{s2} = 494.39 - 114.77 = \mathbf{379.62\ cm.}$$

This value does not agree quite closely with that before found but the tuning was not quite exact in last case.

**Note:** It now seems that the tuning in all previous cases when structure was determined was made to the first octave instead of to the fundamental tone. **This is to be ascertained.** If this be so then capacity would be much **greater.**