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The following papers were read:

Physics. — "*The effect of the induction coil in telephonic apparatus*" (1st part). By J. W. GILTAY. (Communicated by Prof. P. ZEEMAN.)

(Communicated in the meeting of November 30, 1901.)

When HUGHES some twenty years ago announced his invention of the microphone, this simple apparatus at once drew the general attention. Everywhere experiments were made with it. The microphone was connected with a couple of Leclanché-cells and a telephone, and the sound of a ticking watch, etc. was transferred microphonically to the telephone.

When shortly after attempts were made to use the microphone in practical telephony, it was soon made evident that on lines of some resistance the sound emitted was a great deal too faint. The slight changes of resistance taking place in the microphone were of so little importance when compared to the great resistance of the line, that only a slight, practically useless variation of the current appeared in the line.

It was then that EDISON, and at about the same time HOORWEG, found a simple means to overcome this obstacle: the microphone was no longer placed in the line but, with the battery, in the primary circuit of a small induction-coil. The ends of the secondary wire of that coil were connected with the two lines or with line and earth. By an exact selection of the number of secondary turns the undulating current of the battery was transformed into an alternating current of much higher potential, and telephonic messages could be sent over lines of much higher resistance than formerly.

Except for the use of the telephone at distances of but a few hundred metres, not a single telephonic apparatus nowadays is found without induction-coil.

The induction-coils generally used for telephonic purposes, are as a rule provided wich four layers of primary wire, each layer consisting of about 90 turns; the thickness of the wire generally is 0.5 mM. The secondary is usually made of 0.12 mM. thickness and consists of about 3000 turns. In the coil is an iron core.

Practice has shown that such a coil in most cases gives the best results.

The literature about the choice of the induction-coil is very scanty, very few experiments seem to have been made on this subject. In the well-known book of PREECE and STUBBS "a Manual of Telephony" is a table which gives the results of some comparative experiments made by Mr. ABREZOL for the Swiss Telegraphic-Department. The microphone used by him was that of Blake, then in general use; it was connected respectively with ten different induction-coils and then the observed intensity and „clearness" was noted down. The word "clearness" probably denotes the degree of articulation.

The intensity and "clearness" of one of the coils were both indicated by 1; for another coil, e. g. 0.3 was found for the intensity and 0.9 for the "clearness".

The small amount of what is communicated about these experiments in the book of PREECE & STUBBS makes me think, that the figures of the above-named table have not the slightest value.[1]) Estimating the relation of the intensities of 2 sounds by hearing is rather precarious, but how it is possible to express the "clearness" in figures I cannot understand.

In the following lines I wish to give a description of the manner in which I have endeavoured experimentally to investigate whether in reality an increase of the number of primary turns over and above the usual number does not strengthen or improve the telephonic sound. And if that does *not* take place, what may be the reason.

To do so I made 10 different induction coils, described in Table I (page 360). The coils marked A are provided with an iron core, those marked B are not. For the rest, the coils bearing the same number are perfectly alike; so for instance, the only difference between $6A$ and $6B$ is that $6A$ has an iron core and $6B$ has none. When in future I speak of 2 coils, one of which has more primary layers than the other, I shall call the former for simplicity's sake the coil of higher order.

The microphone I used for these experiments was the "Hunnings-Cone", a modification of the Hunnings-microphone. To measure the resistance of this microphone, twelve of them were put in one circuit and the resistance was determined. Then I tapped on all the microphones and the total resistance was again determined and this was repeatedly done. The mean of all these measurements, divided by 12, amounted to about $3^1/_2$ Ohm.

From this microphone the ebonite mouthpiece was screwed off and a resonator, $Fa_3 = 682.6$ s. v., placed before the opening in such a manner that the narrower opening of the resonator was as close as possible to the vibrating plate of the microphone. Before the wider opening of the resonator an electro-magnetic tuning-fork Fa_3 was placed, kept in motion by a small accumulator. Resonator and tuning-fork were both made by KOENIG. With my first experiments the resonator was fastened in a cork ring, fitting in the aperture of the microphone. It was then however evident that the microphone vibrated very irregularly, as regards the intensity. Then the cork ring was removed and the resonator, clasped in a separate stand, was placed before the microphone, so that resonator and microphone-box could not touch each other; I then found that

[1]) I asked Mr. PREECE to inform me where the original description of these experiments was to be found, whereupon he answered me that he was sorry to say he did not remember whence he had the figures.

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TABLE I.

Name of coil	Number of layers of prim. wire.	Number of turns of prim. wire.	Resistance of prim. wire	Thickness of prim wire.	Number of turns of sec. wire.	Resistance of sec. wire.	Thickness of sec. wire.	Length of coil between flanges.	External ϕ of wooden tube on which prim wire is wound	Number of wires of which iron core consists.	Length of iron wires.	Thickness of iron wires
3 A	3	270	0.8	0 5 m.m.	3050	216	0 12	57 m.m.	10.5 m.m.	75	60 m.m.	0 6 m.m.
3 B	3	270	0.8	"	"	214	"	"	"	0		
6 A	6	540	1.85	"	"	247	"	"	"	75	"	"
6 B	6	540	1.9	"	"	253	"	"	"	0		
9 A	9	810	3 2	"	"	316	"	"	"	75	"	"
9 B	9	810	3.2	"	"	295	"	"	"	0		
12 A	12	1080	4.9	"	"	353	"	"	"	75	"	"
12 B	12	1080	4 9	"	"	540	"	"	"	0		
15 A	15	1350	6 5	"	"	363	"	"	"	75	"	"
15 B	15	1350	6.4	"	"	373	"	"	"	0		

the irregularity of the motion of the microphone had much decreased.

The battery used on the microphone generally consisted of one Leclanché-cell.

My original plan was to compare by hearing the effect of my different induction-coils. I therefore placed the vibrating tuning-fork before the microphone and connected by turns one of the two coils under comparison with the microphone and the telephone; of course in such a way that the primary wire was connected with the microphone and the battery, the secondary with the telephone.

However, I soon found that nothing was to be expected of such an investigation, the comparison by hearing of the intensity of 2 tones being exceedingly uncertain, unless the difference of intensity be very great. This is well known from the experiments of VOLKMANN and others [1]), which proved, that the ear does not hear any difference in the intensity of 2 tones, when it is smaller than about 30 per cent.

So I was obliged to compare the induced currents, given by the different coils, to each other in another way, and for this purpose I made use of BELLATI's electro-dynamometer [2]). It is true, that even in this way we cannot yet obtain very accurate figures on account of the great irregularity with which such a microphone and such a tuning-fork work; yet in the following pages it will be seen, that by combining a sufficient number of readings the figures finally speak for themselves.

The electro-dynamometer was provided with 2400 turns, thickness of wire 0.1 m.m., resistance 460 Ohm. The damping was brought about by means of a small circular piece of platinum in concentrated sulphuric acid. To determine the coefficient of damping the instrument was con-

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[1]) WUNDT, Physiologische Psychologie, 3rd edition Vol. I p. 364. This is also easily shown with a simple apparatus, indicated by HEYMANS, "Zeitschrift fur Psychologie und Physiologie der Sinnesorgane", Vol. XXI, p. 351, sub. 1.

It has often astonished me that the innumerable improvements or rather modifications applied to the construction of our magneto-telephones (especially in the first years after BELL's invention) have scarcely any of them found their way. Although many of them were quite impossible, yet there were a few modifications from which something might have been expected. The cause of this is probably to be found in the above-mentioned fact: the reinforcement of the sound of the telephone arising from those improvements, will have been smaller than that minimum-limit.

[2]) Wied. Ann. Neue Folge Vol. XXV, 1885, p. 325. As the instrument nowadays differs in shape so widely from the sketch, given with the above mentioned description, I hereby give the drawing of the apparatus as it is made at present. The iron protecting-ring was not used by me.

nected with the secondary wire of an induction-coil, the primary wire of which being connected with a Leclanché-cell and with that microphone whose tuning-fork had been made to vibrate. As soon as the needle of the electro-dynamometer had undergone a deviation and was nearly in rest in that position, the connection with the secondary wire was broken; the needle oscillated around its original zeropoint and by reading the turning-points the coefficient of damping was determined in the usual manner. It was not possible to determine this coefficient whilst the alternating currents were passing through the instrument on account of the irregular variations in the intensity of these currents. The reader can convince himself of this by calculating K in one of the following tables from p_1 and p_2 or from p_2 and p_3.

The electro-dynamometer was provided with a concave mirror of 50 cm. focal distance. The lamp-stand and scale differed somewhat from that generally used, as is shown in fig. 1. At *c* an electric lamp was placed in the focus of a convex lens, on which a blackened vertical diameter had been drawn. The light of the small lamp was cast upon the concave mirror *a* of the electro-dynamometer and thence reflected to *d*. On the scale *cd* was in the middle the figure 0; the part of the scale on the right hand of 0 I called +, the other —. *ab* is a normal to the scale passing through the centre of the mirror. The scale was not divided into mm. but into smaller parts, (a very inconvenient thing in reading) and in such a way that 1.59 divisions of the scale were equal to 1 m.m. [1]).

During these investigations the electro-dynamometer was 3 times removed from its place and every time when again placed provided with fresh sulphuric acid. The coefficient of damping, the figure where *ab* cuts the scale and the length of *ab* (fig. 1) are therefore different for the different measurements. They were:

for the 1st time	$K = 3.3$	$ab = 1830$	$b = -220$
„ „ 2nd „	$K = 4.5$	$ab = 1700$	$b = -260$
„ „ 3th „	$K = 5.3$	$ab = 1750$	$b = -202$

The first thing I had to do was to investigate whether I might take for granted that with alternate currents of that intensity as

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1) This remarkable lamp-stand was made by Messrs. NALDER BROS & Co. London. „Theuer und schlecht", to use the wellknown verdict of Prof REULEAUX, with a slight modification

they were used by me, the deviations of the electro-dynamometer were proportional to the square of the mean intensity of the current. I set to work as indicated in fig. 2.

The microphone was connected with an accumulator and the primary wire of coil 3 A. As is the case with all the experiments described in this paper, the resonator Fa 3 and the tuning-fork Fa 3 were placed before the microphone. One of the ends of the secondary wire of 3 A was connected with the electro-dynamometer and moreover with the pivot of a Morse-key; the other end of the secondary wire with the pivot of a 2nd Morse-key. The contacts of rest of the keys were connected with each other; the working contacts likewise, but with *that* wire were connected: 1°. a coil of wire, *a*, in which a bundle of ironwires was placed under an angle of 45 degrees to the plane of winding, quite similar to the coil and the bundle of ironwires of the electro-dynamometer; 2°. the secondary wire, *b*, of coil 3 B, into which however for this experiment an iron core had been put.

If the Morse-keys were not pressed down, the current induced in 3 A passed to the electro-dynamometer and thence along 9, 5, 6, 10 back to the secondary wire. If however both keys were pressed down, the current had to pass along 9, 1, *a*, *b*, 2, 10 and so passed through a 2nd Bellati-coil and a 2nd secondary wire. In that case the resistance as well as the self-induction of the secondary circuit was doubled and consequently the strength of the current reduced to half its former intensity.

The relation between current-strength and deviation I have determined for three different currents. In the first case the deviations with the currents i and $2\,i$ were respectively 118'.9 and 481'.7; in the second case those deviations were 93'.1 and 350'.4 and in the third case 21'.9 and 85'.1.

Three successive turning-points were always observed; the position of rest was calculated according to the well known formula $p_0 = p_2 + \frac{p_1 - p_2}{1+k}$, from p_1 and p_2 as well as from p_2 and p_3. A further description is superfluous on account of Table II (p. 364), giving the entire measurement of the 2nd of the above-mentioned cases.

In this way I found in the three different measurements the numbers 4.05, 3.76 and 3.89 for the relation between the deviations brought about by the currents $2\,i$ and i. The mean of these three values is 3.9. So for our further measurements we can assume

TABLE II.

Zeropoint before the experiment + 311 } mean + 312
" after " " + 312 }

Strength of current.	p_1	p_2	p_3	*a* calculated position of equilibrium from p_1 and p_2.	*b* id. from p_2 and p_3.	*c* $\frac{a+b}{2}$	*d* deviation for $2i$ (from *c*).	*e* mean of 2 successive *d*.	*f* deviation for *i* (from *c*).	*g* mean *e*	*h* mean *f*	*i* *g* in minutes.	*k* *h* in minutes.	$\frac{i}{k}$
$2i$	— 137	— 17	— 56	— 45	— 47	— 46	358							
i	+ 256	+ 184	+ 211	+ 201	+ 205	+ 203		386	109					
$2i$	— 223	— 75	— 100	— 109	— 94	— 102	414							
i	+ 252	+ 181	+ 218	+ 198	+ 209	+ 203		415	109					
$2i$	— 181	— 76	— 121	— 100	— 111	— 105	417							
i	+ 286	+ 186	+ 199	+ 209	+ 196	+ 202		404	110	387	106	350'.4	93'.1	3.76
$2i$	— 130	— 63	—	— 79	—	— 79	391							
i	+ 268	+ 185	+ 201	+ 204	+ 197	+ 200		386	112					
$2i$	— 99	— 43	— 94	— 56	— 82	— 69	381							
i	+ 224	+ 215	+ 226	+ 217	+ 223	+ 220		346	92					
$2i$	— 93	+ 28	— 5	0	+ 3	+ 1	311							

Damping = 3 3, *ab* (fig. 1) = 1830, Point of intersection *b* (fig. 1) = — 220.

with sufficient accuracy that the deviations of the electro-dynamometer are proportional to the square of the mean current.

To investigate which of the induction-coils named in Table I, connected in the usual way to a telephonic apparatus, would give the strongest induction-current I set to work in the following way:

In the first place only coils with iron were compared with one another. In fig. 3, K and K 1 are the coils to be compared. I, II, III and IV are Morse-keys which by means of a simple arrangement can be all pressed down at the same time. In the position of rest the keys themselves are connected with the upper contacts; *cc* is a double switch by which the current flowing to the electro-dynamometer can be opened or shut. R is a rheostat, shunted to the coil of the electro-dynamometer to reduce the deviations to a suitable size. As is easily seen from the figure, coil K1 is connected with the electro-dynamometer and with the microphone, as long as the keys are *not* pressed down; when the keys *are* pressed down, coil K is connected with the electro-dynamometer and with the microphone. All contacts not being broken or made by the four keys exactly at the same time when the coils were interchanged, care was taken that the commutator *cc* was always opened a little time before the keys were pressed down and before they were relinquished again, as otherwise strong induction-currents might find their way to the electro-dynamometer, which would give rise to remanent magnetism in the bundle of iron wires and a great modification of the zero-point.

In the first place I have compared coil 3 A with 6 A, 9 A, 12 A and 15 A and after that again 6 A with 9 A, 9 A with 12 A and 12 A with 15 A.

Table III (p. 366) shows how the experiment to compare 3 A with 6 A was made; in quite the same way the six other measurements were made. From the first four measurements I got for the proportion of the intensity of the induced currents given by our five coils:

Coil:	3 A	6 A	9 A	12 A	15 A
Intensity of the induced current:	1	1.507	1.429	1 114	0.818

TABLE III.

Zeropoint before the experiment + 325 } mean + 328.
″ after ″ ″ + 330 }

Coil.	p_1	p_2	p_3	*a* calculated position of equilibrium from p_1 and p_2.	*b* id. from p_2 and p_3.	*c* $\frac{a+b}{2}$	*d* deviation for 3 A (from *c*).	*e* mean of 2 successive *d*.	*f* deviation for 6 A (from *c*).	*g* mean *e*	*h* mean *f*	*i* *g* in minutes.	*k* *h* in minutes.	$\sqrt{\frac{k}{i}}$
3 A	+ 44	+ 107	+ 92	+ 92	+ 96	+ 94	234							
6 A	— 259	— 115	— 158	— 148	— 148	— 148		223	476					
3	+ 67	+ 131	+ 113	+ 116	+ 117	+ 116	212							
6 A	— 300	— 127	— 187	— 167	— 173	— 170		211	498					
3 A	+ 36	+ 138	+ 113	+ 114	+ 119	+ 117	211							
6 A	— 256	— 95	— 139	— 133	— 129	— 131		209	459	212	470	188′	427′	1.507
3 A	+ 43	+ 144	+ 115	+ 120	+ 122	+ 121	207							
6 A	— 244	— 86	— 140	— 123	— 127	— 125		209	453					
3 A	+ 42	+ 137	+ 112	+ 115	+ 118	+ 117	211							
6 A	— 255	— 99	— 145	— 136	— 134	— 135		210	463					
3 A	+ 35	+ 139	+ 113	+ 115	+ 119	+ 117	211							

Damping = 3,3, *ab* (fig 1) = 1830, point of intersection *b* (fig. 1) = — 220.

From this we find:

$$\frac{9\,A}{6\,A} = 0.95 \qquad \frac{12\,A}{9\,A} = 0.78 \qquad \frac{15\,A}{12\,A} = 0.74.$$

And from the 3 last measurements I got:

$$\frac{9\,A}{6\,A} = 0.782 \qquad \frac{12\,A}{9\,A} = 0.761 \qquad \frac{15\,A}{12\,A} = 0.775.$$

For the value of $\frac{9\,A}{6\,A}$ the two results do not agree very nicely; as for $\frac{12\,A}{9\,A}$ and $\frac{15\,A}{12\,A}$, the correspondence is very good.

So now we know, that by increasing the number of primary turns of the induction-coil we soon reach a maximum for the intensity of the induced current and that by continuing to increase the number of turns we arrive at a decrease in the strength of the induced current.

It was obvious to think, while searching for an explanation of this phenomenon, of the possibility that the iron in the coils of higher order would be much nearer to its magnetic saturation point than in the coils of lower order. In that case the undulations of the microphone-current would bring about, in coil 15 A for instance, smaller variations in the magnetism of the iron than would be the case in coil 3 A.

This current of thoughts led me to compare the coils with iron with those without iron as regards the intensity of the induced currents furnished by them. The method I followed for this was just the same as the one I had followed for getting Table III.

The result of this investigation is found below. If we call A the current induced by a coil with iron and B the current induced by a coil of the same order but without iron, we then find:

For coil:	3	6	9	12	15
The value for $\frac{A}{B}$:	5.56	3.95	2.59	1.95	1.48
or for the efficiency of the iron, if we take that for coil 3 A to be equal to 1:	1	0.71	0.47	0.35	0.27

We see from these numbers that the influence of the iron on the intensity of the induced current is much less in the coils of higher order than in those of lower order. And comparing these numbers with those we gave on page 11 for the value of A we see that the decrease of the effect of the iron between 3 A and 6 A is still compensated by the increase of the number of primary turns, but that higher than 6 A the decrease of the effect of the iron predominates and that the increase of the number of turns is then no longer sufficient to make good that decrease.

To investigate whether in reality an approach to saturation of the iron may be regarded as the cause of this phenomenon, the magnetism of the iron core of coil 15 A was investigated as follows for different currents: In fig. 4, M is a bell-magnet hanging on a fibre in a copper damper. In the line *ab* perpendicular to the magnetic axis the coils 15 A and 15 B were placed. First the iron core was taken out of coil 15 A, then the two coils, 15 A (without iron) and 15 B, were placed at such distances from the magnet, that a current of 1 Ampère, traversing both in opposite directions, did not give a deviation to the magnet. Now the iron core was again put into coil 15 A and the latter laid in exactly the same place as before. The distance from the centre of the bell-magnet to the middle of the iron core was 307 mm.

Now the Morse-key was pressed down; as soon as the index attached to the magnet stopped, the position was read, and at the same time the Ampère-meter was read by a second observer. This was a- necessary precaution, because, at least when using strong currents, the index of the magnet as well as that of the Ampere-meter slowly went back to zero in consequence of the increase of resistance of the coils caused by the heating of the wires. To be quite sure that the coils had not been damaged by the strong currents, the iron was removed out of 15 A after the measurements were made and a current of 1.5 Ampère led through the two coils in opposite direction: the magnet remained in its position of equilibrium just as at the beginning of the experiment before the iron was put into 15 A.

Fig. 5 represents the results of these measurements in the form of a curve; the ordinates are proportional to the magnetic intensity, the abscissae to the strength of the current. The figure shows, by the small circles, that I have taken fifteen readings with a strength of current, increasing from 0.11 to 1.53 Ampère. α is the angle between the magnetic axis of the magnet and the magnetic meridian.

Now the current in the primary wire of 15 A, connected with the microphone (in rest) and a Leclanché-cell amounts to about 0.08 Ampère. The curve of fig. 5 shows clearly that there is not the slightest question about the iron being saturated when the current has this intensity.

I then considered whether the iron might not become *slower* in changing its magnetic condition if the magnetism reached a higher degree, even though there were no question about an approaching saturation. That in other words a piece of iron would need more time to change its magnetism from 20 to 18 or 22 than from 6 to 8 or 4.

To investigate this the experiment shown in fig. 6 was made.

T is a translator without iron core, consisting of 2 × 1500 turns; thickness of wire 0.4 mM.; resistance of each of the two series of turns about 21.5 Ohm. The battery consists of a number of secondary cells, of which I used respectively 1, 4, 8 and 11 cells in the four different sets of experiments I made with this apparatus. For the rest the sketch speaks for itself. If the Morse-key was *not* pressed down, a telephonic alternating current passed through the primary wire of 15 A; if on the contrary the key *was* pressed down, a constant current also passed through it.

For the proportion between the strength of the current, induced in the secondary wire, if only an alternate current passed through the primary wire, to that of the induced current when also a constant current passed through the primary wire, I found:

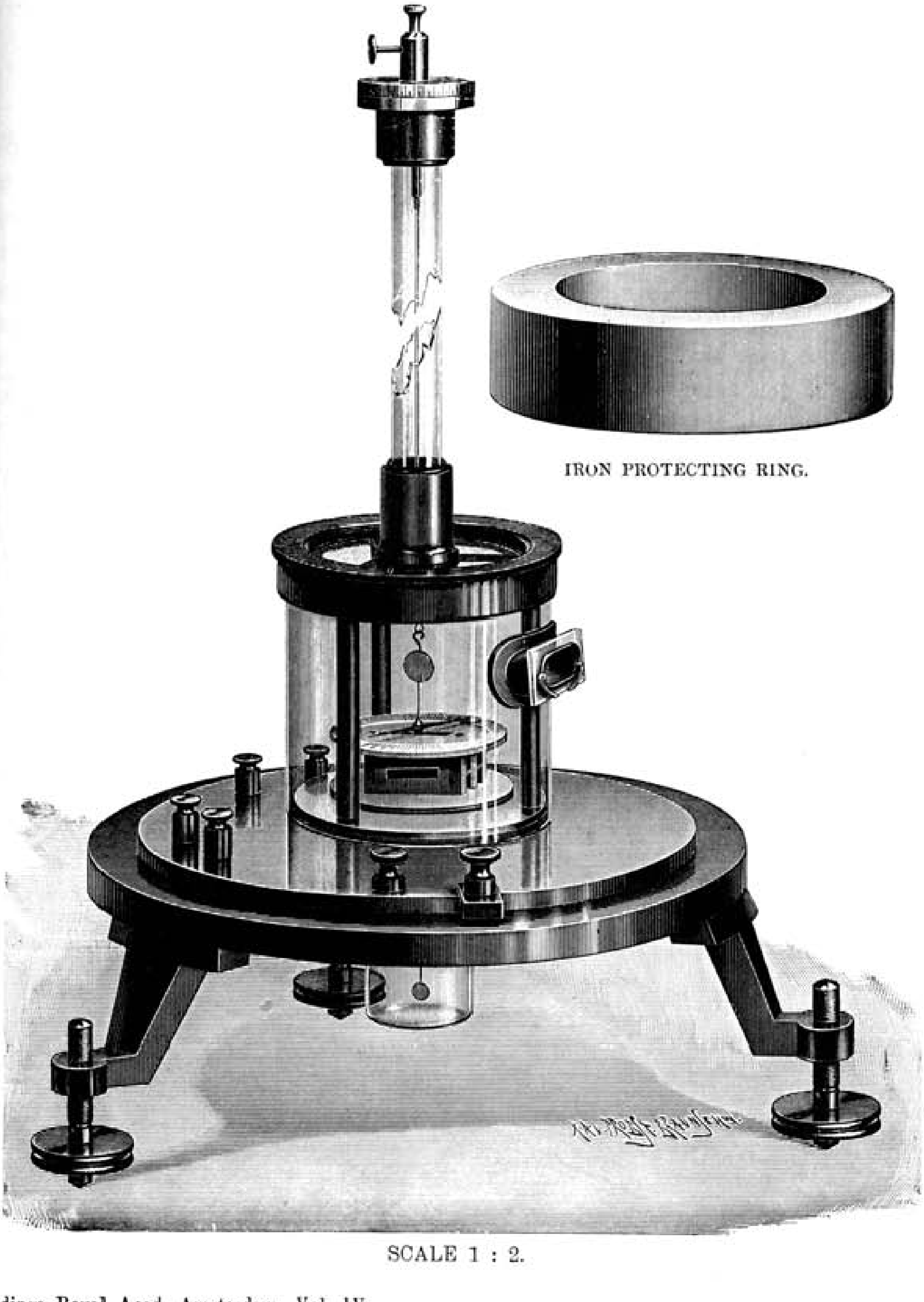
for the currents:	0.08	0.35	0.66	0.88 Ampère,
the proportion:		0.997	0.981	1.01	1.149.

The number of readings and the calculation of the mean value were for these measurements quite similar to those given in Tables II and III.

From the above it is evident that the constant currents 0.08, 0.35 and 0.66 Ampère have no perceptible influence on the intensity of the induced current. Not until the strength of the current was 0.88, did this influence become perceptible: there the induced current becomes distinctly feebler when the constant current flows through the coil. But with that strength of current the magnetism is no more proportional to the intensity of the current, as the curve of fig. 5 shows. The slowness of the iron cannot now be regarded as the cause of the induced current becoming feebler, but, with such a current, this can be explained from the saturation

PLATE I.

J. W. GILTAY „The effect of the induction-coil in telephonic apparatus." (I).



SCALE 1 : 2.