XLVIII. On the alterations in the electrical resistances of metallic wires, produced by coiling and uncoiling

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As may be seen, the curves A and B for both plates approach one another very nearly. The greatest difference between two corresponding ordinates is about 1 per cent., or not more than the differences which have occurred in experimenting with the slice in one position.

From this the inference may be drawn that a unilateral conductivity for heat is present in tourmaline either to a very small degree or, what seems more probable, not at all.

Phys. Inst. Univ. Strassburg,
May 1884.

XLVIII. *On the Alterations in the Electrical Resistances of Metallic Wires, produced by Coiling and Uncoiling.* By JAMES HOPPS, *Superintendent of Workshops, Royal Indian Engineering College, Cooper's Hill**.

[Plate IX.]

DURING the past winter, while assisting a pupil to make some resistance-coils, I was struck with the great difference that often existed between the resistance of the wire before it was coiled on to its bobbin and after; the difference was not always constant or proportional to the length of the wires used, and appeared to be largely influenced by the tension with which the wires were coiled on to the bobbins.

Some of the coils altered so much after winding as to lead to the supposition of their being short-circuited; and on uncoiling several of these and recoiling at a lower tension, the resistance would alter considerably.

The diameter of the bobbin used also appeared to have great influence in producing changes in the resistance.

A great portion of the alterations appeared to be temporary.

As has been observed above, the differences were not always constant; neither were they regular in their signs, *i. e.* they would sometimes show an increase and sometimes a decrease of resistance, but generally the change would be one of increase.

Having resolved to make some efforts to clear up this matter, I first sought to find what had been done by others in this direction. A very careful search through books and also of the Transactions of the Royal Society afforded no evidence that this field had been even entered upon, *i. e.* any attempt by experiment or otherwise to determine and account for the effects of coiling and uncoiling on the electrical resistance of metallic wires.

After experimenting some weeks, I purposely attended the meeting of this Society on February 23rd to hear a paper,

* Communicated by the Physical Society.

"On the Adjustment of Resistance-Coils," by Prof. Silvanus P. Thompson; and although some of the difficulties in the way of adjusting resistance-coils were spoken of, yet the difficulty that had given us so much trouble was not once alluded to, either in the paper or in the discussion which followed. At the close of the proceedings, in the course of a short conversation with Prof. Thompson, and in reply to a question from myself, he stated that he had observed that the resistance of a wire was altered by being coiled. Mr. Latimer Clark also observed that he had noticed the change, but added that the changes were not always constant, giving sometimes an increase and sometimes a decrease in the resistance. Now experiments had given me the same results, and had the subject cropped up during the discussion, I had prepared a few notes to give to the meeting.

The fact of having obtained sometimes + and sometimes — readings had puzzled me much, but after the conversation above alluded to I resolved to continue my experiments; and although these are yet far from complete, I have felt it my duty to lay the results already obtained before the Society.

Before going into a description of the apparatus and method employed (part of the apparatus is before you), I would crave a few moments to allude to some of my earlier experiments. These were conducted in a very primitive way; but the results obtained, although appearing so erratic and contradictory, have been in a great measure confirmed by using the more elaborate method employed later on. In confirmation of this I would draw your attention to the great resemblance which exists between the two curves on the diagram, which are the curves of copper wires produced by hand- and machine-winding respectively.

The method first employed to investigate this effect was to let the wire under test form one side of a Wheatstone bridge, doubling the wire into a loop as in a resistance-coil, and rolling it by hand on to a cylinder or other shapes in wood. The resistance could thus be taken after each operation without the necessity of altering the connexions.

The time lost in waiting until the heat imparted to the wire through handling had disappeared was great, and the uncertainty as to the tension with which the wire was coiled and uncoiled caused me to seek some other method.

After many schemes the one before you was adopted. Bearing in mind that many of the wires to be experimented upon would not be insulated, and would be of many different diameters and rigidities, it was very early evident that the drum on which the wires were to be coiled would also have to insulate each convolution from its neighbour as well as to wind up

the wire. The different diameters and rigidities also determined the necessity of being able to vary the tension. The insulation is obtained by using an ebonite drum to receive the wire ; on this drum a right- and left-handed screw has been cut. The variation in the tension may be obtained in two different ways, or by a combination of both:—1st, by altering the load carried in the little waggon which runs up and down the inclined plane ; 2nd, by altering the angle of inclination of the plane ; or we may combine both if necessary.

As the application of longitudinal strain to a wire while being tested for resistance has been shown to be considerable, it was necessary to relieve the wire from the strain due to the load before taking the resistance, otherwise the changes due to strain would have been included in the readings. To remove the strain, the waggon on arriving at the bottom of the plane rests against a stop ; on being drawn to the top the plane is brought to a position slightly above the horizontal ; these allowing in both cases the drum to slightly unwind itself, and consequently the strain on the wire is almost entirely removed.

The ebonite drum, as before observed, has a right- and left-handed screw cut upon it ; these meet in the middle of its length. A screw holding down an ebonite cap here passes through the inside of the loop of the wire under test, and fixes it firmly, but without injury, to the drum ; the ends of the wire are carried up the plane to two binding-screws, and with the necessary leading wires form one side of a Wheatstone bridge.

A long length of stout whipcord is attached to the middle of a winding drum underneath the head of the plane, and the ends, after being coiled between the empty threads of the ebonite drum (starting from the centre), are fixed to the ends of the drum. On turning the drum below, the cords pull on the top part of the ebonite drum, causing it to revolve ; and at the same time that the cord is being payed off, the wire under test is being coiled on in its place. This is continued until the waggon arrives at the top ; a pawl working on a ratchet-wheel prevents the waggon running back until the plane has been brought to a horizontal position, where, after resting five minutes, the resistance is taken. The operations are now reversed ; and after a similar rest at the bottom, the resistance is again taken. And these operations are repeated, each operation taking about six minutes, giving an average of ten per hour ; they were generally continued for three hours, giving for each series about thirty readings, and then allowed to stand until the following evening, all strain being previously removed.

The temperature of the laboratory was carefully regulated each evening, for two hours before commencing work, to the

same temperature as on the previous evening, and kept constant within half a degree Fahr. $\pm$.

In the case of some wires as many as 380 readings have been taken altogether; this was on lead wire No. 5. At the end of the seventh series the wire broke.

The curves of resistance of four of the seven series of tests on this wire is very interesting. It will be observed that, while being very similar to each other, there is a point marked (*a*) on each series where coiling and uncoiling produce an increase in the resistance. Again, the wonderful power of recovery which is shown by the wire after each rest is very marked; the normal condition would appear to be to give positive and negative readings, and that this condition is upset after a time. The inability to recover this condition has suggested that, when this point has been arrived at, it might be said to represent the commencement of a kind of electrical fatigue.

There are some other points on this diagram, and which are more or less repeated by every other wire that I have tested, which furnish matter for speculation; such as—why should coiling generally produce a less effect than uncoiling? and why should the signs be generally different? and why should those signs in many cases become reversed?

An *increase* of resistance on uncoiling and a *decrease* on coiling take place with lead, copper, German silver, aluminium, and magnesium; and also with the first few operations on soft iron wire, after which the signs are completely changed.

An increase almost invariably follows coiling and uncoiling with zinc, but the effect of coiling varies from one half to one thirtieth of the effect of uncoiling.

The difference between coiling and uncoiling, or, we might say, the amplitude of the differences of resistances, is greatest in the case of magnesium and least in the case of aluminium; the latter, on referring to the curves, will be seen to alter very little indeed.

The amplitude of the differences in the case of hard-drawn German silver is not so great after a few series; and when annealed, after showing great increases after standing at rest, the final series approach very near to that of the hard-drawn wire, which is strong evidence indeed that the wire has become harder through repeated coiling and uncoiling.

The length of the wires were very carefully taken before and after the experiments, and the necessary calculations made for alterations in length and cross-section according to the formula

$R \propto \frac{l}{a}$, in which R = the resistance, l = the length, and a = the area of the cross section.

After making these corrections, the changes in the resistance remaining unaccounted for are:—

Metals.	Of the increase on the original resistance.	Of the actual observed change.
Iron	2·3 per cent.	81·64 per cent.
Lead (average of six)	1·27 „	2·91 „
Copper	1·18 to 1·42 per cent.	57·58 to 60·7 per cent.
Zinc	1·23 to 2·16 „	23·6 to 42·4 „
Aluminium	0·77 to 2·206 „	41·15 to 72·01 „
German silver (annealed) ...	0·054 to 0·171 „	11·89 to 21·6 „
Magnesium No. 2.....	1·549 per cent.	

With magnesium No. 2, from a different sample from No. 1, the wire became shorter; and the resistance, which should have fallen ·0745 per cent., actually increased 1·475 per cent., being equivalent to a difference of 1·549 per cent. on the original resistance unaccounted for.

With magnesium No. 1 the actual increase of resistance amounted to 2·16 per cent. on the original resistance, whereas theoretically it should have increased 3·39 per cent., or 1·23 per cent. greater than really took place; or we may say that of the theoretical increase only 54·35 per cent. was visible, showing that the specific conductivity of the wire had risen. Four portions of this wire were tested, and the results were all very near alike.

On examining the results obtained with German silver No. 5 (annealed), which after all is most likely to interest us, owing to its employment in resistance-coils, we find that the total increase was equal to ·454 per cent.; and after deducting ·4 per cent., which is due to increase in length and diminution of section, there still remains unaccounted for ·054 per cent. on the original resistance, or 11·89 per cent. of the whole observed change.

With German silver (hard-drawn) the results are very curious. Here the length actually decreased; and on making the necessary corrections, the resistance should have shown a decrease of ·284 per cent.; but the actual decrease was only equal to ·036 per cent., not low enough by ·248 per cent.; or we may say that of the theoretical decrease only 12·26 per cent. was visible.

On examining the curves from the iron wires Nos. 3 and 4, it will be observed that at the commencement uncoiling produced a very large *increase*, while coiling produced a small *decrease*; but after sixteen operations in one case and twenty-

one in the other, the signs became reversed, and this continued throughout the remaining series of the two wires.

On page 74, vol. vi. of the 'Proceedings of the Physical Society,' I find a paper by Mr. Herbert Tomlinson, in which he says that "the behaviour of nickel is especially worthy of notice, because in it longitudinal traction, when not carried beyond a certain limit, *diminishes* the electrical resistance in spite of the increase of length and diminution of section which ensues."

I have not been able to obtain wires in nickel, but, according to the results obtained, some samples of magnesium appear to have the same property.

At the last moment Prof. Stocker has shown me that in *Die Electricität*, by Wiedemann, it is noted that "the coiling of a copper or iron wire increases, whilst the uncoiling diminishes the specific resistance about 0.003 of the total value of the same."

And, again, in *Die Physik*, vol. iii., by Mousson, that "the coiling of a wire upon a cylinder slightly increases the resistance, in consequence, as is supposed, of tension; uncoiling diminishes it again. Under similar circumstances, the changes amounted to 0.0032 in the case of copper and to 0.0056 in iron, of their total resistances."

It will be observed that both these descriptions are contrary to what I must conclude from my own experiments.

Having made some inquiries from a friend of mine who had charge of the testing department in the cable factory of J. B. Pirelli, F. Casassa et Cie, of Milan, he has supplied me with data which show that the specific conductivity of the copper conductors have fallen in many cases $1\frac{1}{2}$ per cent. during manufacture, and when encased in lead tubes they have often fallen over 2 per cent. In all cases the necessary corrections have been made for increase of length and diminution of section due to strain in passing through the covering machines. Possibly the greater loss in the lead-encased core may be due to a damping-effect from the lead, but the bulk of the increase of resistance must be due to some other cause. These cables were manufactured under very strictly enforced conditions for the Italian State Telegraph-stores; and the tests taken by government officials, ten weeks after they had been sent from the factory, were in all cases within 0.2 per cent. of the final tests in the factory, showing conclusively that the changes were in a great measure permanent.

I have therefore come to a very decided conclusion that the changes in the resistance are not altogether the result of changes in form, and that their cause must be sought for elsewhere.

Many theories have suggested themselves, but none are entirely satisfactory.

One theory was that, in coiling, the decrease of resistance was due to a thickening of the wire on its internal side and a thinning of the external side, thus bringing the centre of area inwards, and so making the actual distance the current would have to travel shorter, which would be equivalent to making the wire shorter; and then on uncoiling, the displacement of the molecules, due to slipping on each other when seeking to regain their original position, would have the effect of increasing their distance apart, and consequently increasing the resistance. But the weak point in this theory is that it will not account for the change of signs which so often takes place, nor will it account for the zinc wires giving increased resistances on coiling.

Another theory, which appears more promising, was that, while being coiled and uncoiled, the wires were subject to strains of a torsional kind, which might be due to their having a certain amount of residual twist in them, owing to the way in which they have been coiled on to the drums on the bench of the wire drawer; and that on being coiled and uncoiled on their bobbins this twist might be increased or decreased, so giving different amounts in the resistance. But from experiments I have made, which seem to me quite conclusive, it appears that although there is a certain amount of twisting and untwisting produced by being wound on to the bobbins, yet this fails to account for the residue of the observed changes.

With reference to the effects on the permanency of value of a set of resistance-coils which are only subjected to one winding, I have not yet sufficient data to lay before you; but, so far as I have gone into this part of the subject, I believe that the immediate alterations on coiling the wires on the bobbins are to a great extent affected by the tension and the speed with which they are wound, the thickness and kind of insulator employed (cotton-covered wires appear to be less affected than silk-covered wires), and also by the diameter of the bobbins on which the wire is wound (the smaller the bobbin the greater the alteration). But further experiments are necessary to put these beyond doubt.

Appended to this paper are a few tables showing the actual readings in the first series of several of the wires tested (these readings include the resistance of the leading wires, .0274). These, together with the curves (Pl. IX.), may be of some service in assisting to a conclusion as to the probable cause of the changes in the resistance of wires produced by coiling and uncoiling.

*Actual Readings and Differences produced by Coiling and
Uncoiling of Lead Wire No. 5 (first four series only).*

U represents uncoiled ; C represents coiled.

	1st Series.		2nd Series.		3rd Series.		4th Series.	
	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.
U	2923		3087		3198		3340	
C	22	+0001	88	+0001	3196	-0002	39	-0001
U	33	+0011		+0015	3213	+0017	56	+0017
C	32	-0001	3103	+0001	11	-0002	52	-0004
U	39	+0007	12	+0008	28	+0017	64	+0012
C	40	+0001	20	+0008	26	-0002	60	-0004
U	45	+0005	23	+0001	37	+0011	72	+0012
C	47	+0002	28	.....	35	-0002	68	-0004
U	52	+0005	36	+0008	42	+0007	78	+0010
C	54	+0002	37	+0001	42	.....	77	-0001
U	59	+0005	43	+0006	49	+0007	86	+0009
C	61	+0002	44	+0001	49	.....	85	-0001
U	67	+0006	49	+0005	57	+0008	93	+0008
C	69	+0002	51	+0002	57	.....	93	.....
U	73	+0004	57	+0006	64	+0007	3400	+0007
C	77	+0004	58	+0001	64	.....	00	.....
U	81	+0004	63	+0005	72	+0008	5	+0005
C	84	+0003	64	+0001	73	+0001	7	+0002
U	88	+0004	69	+0005	78	+0005	14	+0007
C	91	+0003	71	+0002	79	+0001	16	+0002
U	94	+0003	77	+0006	86	+0007	20	+0004
C	98	+0001	80	+0003	87	+0001	22	+0002
U	3001	+0003	85	+0005	93	+0006	26	+0004
C	4	+0003	87	+0002	94	+0001	28	+0002
U	7	+0003	92	+0005	99	+0005	32	+0004
C	10	+0003	94	+0002	3300	+0001	36	+0004
U	14	+0004	98	+0004	5	+0005	39	+0003
C	17	+0003			6	+0001	41	+0002
U	20	+0003	Rested here 21 hours ; no change on resuming.		12	+0006	43	+0002
C	24	+0004			14	+0002	46	+0003
U	28	+0004			19	+0005	49	+0003
C	30	+0002			20	+0001	53	+0004
U	34	+0004			25	+0005	56	+0003
C	38	+0004			27	+0002	59	+0003
U	40	+0002			33	+0006	62	+0003
C	42	+0002			36	+0003	65	+0003
U	45	+0003			40	+0004	68	+0003
C	47	+0002					71	+0003
U	51	+0004	Rested here 22 hours ; no change on resuming.				75	+0004
C	56	+0005					79	+0004
U	59	+0003					82	+0003
C	62	+0003					85	+0003
U	66	+0004					87	+0002
C	69	+0003					90	+0003
U	66	+0003					93	+0003
C	70	+0004					96	+0003
U	76	+0006					99	+0003
C	79	+0003					3502	+0003
U	83	+0001					5	+0003
C	87	+0004					8	+0003
U	90	+0003					9	+0001
C	90	.....						
								Loss after standing 21 hours=0003.

Aluminium Wire.

No. 1.				
1st Series.			2nd Series.	
	Resistance.	Difference.	Resistance.	Difference.
U ...	·08004	.....	·08042	—·00005
C ...	4	+·00018	37	+·00011
U ...	22	—·00007	48	—·00006
U ...	15	+·00011	42	+·00007
U ...	26	—·00008	49	—·00006
C ...	18	+·00010	43	+·00010
U ...	28	—·00006	53	—·00006
U ...	22	+·00010	47	+·00011
U ...	32	—·00007	58	—·00005
O ...	25	+·00009	53	+·00008
U ...	34	—·00007	61	—·00005
C ...	27	+·00010	56	+·00008
U ...	37	—·00011	64	—·00005
U ...	26	+·00009	59	+·00008
U ...	35	—·00005	67	—·00004
C ...	30	+·00008	63	+·00006
U ...	38	—·00005	69	—·00003
C ...	33	+·00008	66	+·00005
U ...	41	—·00006	71	—·00003
U ...	35	+·00009	68	+·00004
U ...	44	—·00005	72	—·00004
C ...	39	+·00007	68	+·00005
U ...	46	—·00004	73	—·00004
U ...	42	+·00006	69	+·00005
U ...	48	—·00004	74	—·00003
U ...	44	+·00005	71	+·00005
U ...	49	—·00003	76	—·00003
C ...	46	+·00006	73	+·00004
U ...	52	—·00004	77	—·00003
U ...	48	+·00007	74	+·00004
C ...	55	—·00003	78	—·00003
U ...	52	+·00008	75	+·00004
U ...	60	—·00004	79	—·00003
C ...	56	+·00005	76	+·00005
U ...	61	—·00003	81	—·00003
U ...	58	+·00003	78	+·00005
U ...	61	—·00002	83	—·00004
U ...	59	+·00003	79	+·00003
C ...	62	—·00002	82	—·00003
U ...	60	+·00003	79	+·00003
U ...	63	—·00002	82	—·00002
C ...	61	+·00002	80	+·00002
U ...	63	—·00001	82	—·00002
U ...	62	+·00002		
U ...	64	—·00001		
U ...	63	+·00001		
U ...	64	.....		
U ...	64	+·00001		
U ...	65	.....		
C ...	65	+·00001		
U ...	66			

Rested here 21 hours; loss
by standing ·00023.

Rested here 45 hours; and
gained by standing ·00019.

German-silver Wires.

	No. 4 (hard drawn).				No. 5 (annealed).			
	1st Series.		2nd Series.		1st Series.		2nd Series.	
	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.
U...	1·53483		1·53541		1·51821		1·52150	
C...	25	-·00058	445	-·00096	982	+·00161	140	-·00010
U...	62	+·00037	552	+·00107	963	-·00019	150	+·00010
C...	12	-·00050	458	-·00094	981	+·00018	142	-·00008
U...	65	+·00053	545	+·00087	980	-·00001	149	+·00007
C...	13	-·00052	468	-·00077	980	.....	138	-·00011
U...	60	+·00047	556	+·00088	980	.....	150	+·00012
C...	05	-·00055	471	-·00085	992	+·00012	136	-·00014
U...	45	+·00040	530	+·00059	992	.....	130	+·00006
C...	02	-·00043	485	-·00045	988	-·00004	122	-·00008
U...	42	+·00040	524	+·00039	988	+·00012	140	+·00018
C...	03	-·00039	480	-·00044	1·52000	-·00006	123	-·00017
U...	42	+·00039	518	+·00038	1994	+·00010	135	+·00012
C...	05	-·00037	482	-·00036	2004	-·00004	120	-·00015
U...	41	+·00036	516	+·00034	2000	+·00010	132	+·00012
C...	00	-·00041	478	-·00038	2010	-·00007	119	-·00013
U...	40	+·00040	501	+·00023	2003	+·00017	129	+·00010
C...	00	-·00040	472	-·00029	2020	-·00010	129	-·00018
U...	36	+·00036	499	+·00027	2010	+·00015	111	+·00009
C...	00	-·00036	66	-·00033	2025	-·00011	120	-·00012
U...	35	+·00035	85	+·00019	2014	+·00017	108	+·00006
C...	1·53396	-·00039	59	-·00026	2031	-·00010	114	-·00014
U...	434	+·00038	80	+·00021	2021	+·00017	100	+·00015
C...	395	-·00039	52	-·00028	2038	-·00011	085	-·00012
U...	434	+·00039	73	+·00021	2027	+·00013	073	+·00011
C...	394	-·00040	37	-·00036	2040		062	-·00011
U...	423	+·00029	62	+·00025			068	-·00006
C...	390	-·00033	48	-·00014			071	+·00003
U...	421	+·00031	62	+·00014			065	-·00006
C...	390	-·00031	34	-·00028			070	+·00005
U...	425	+·00035	58	+·00024			070	.....
C...	391	-·00034	31	-·00027			071	+·00001
U...	425	+·00034	52	+·00021			070	-·00001
C...							072	+·00002
U...							070	-·00002
C...							073	+·00003
U...								
	Rested for 21 hours; gained ·00116.		Rested for 21 hours; gained ·00109.		Rested for 16 hours; gained ·00110.		Rested for 26 hours; gained ·00231.	

Magnesium Wires.

No. 1. Length at commencement =55.08 inches.				No. 2. Length at commencement =86 inches.								
1st Series.		2nd Series.		1st Series.		2nd Series.						
Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.					
U...	29195	-00135	29488	-00104	44079	-00264	14312	-00164				
C...	60	+00150	384	+00141	3815	+00333	148	+00220				
U...	210	-00135	525	-00115	4148	-00215	368	-00163				
C...	75	+00150	410	+00145	3933	+00283	205	+00199				
U...	225	-00127	555	-00128	4216	-00225	404	-00172				
C...	98	+00157	427	+00140	3991	+00254	232	+00149				
U...	255	-00110	567	-00122	4245	-00222	381	-00158				
C...	145	+00120	445	+00122	4023	+00234	223	+00162				
U...	265	-00110	567	-00132	257	-00195	385	-00154				
C...	155	+00125	435	+00130	062	-00210	231	+00155				
U...	280	-00100	565	-00100	272	-00181	386	-00151				
C...	180	+00123	465	+00110	091	+00209	235	+00145				
U...	303	-00125	575	-00102	300	-00174	380	-00138				
C...	178	+00099	473	+00112	126	+00199	242	+00139				
U...	277	-00091	585	-00103	325	-00157	381	-00140				
C...	186	+00098	482	+00112	168	+00062	241	+00143				
U...	284	-00099	594	-00106	230	-00142	384	-00138				
C...	185	+00107	488	+00117	088	+00160	246	+00135				
U...	292	-00087	605	-00109	248	-00167	381	-00139				
C...	205	+00090	496	+00114	081	+00170	242	+00138				
U...	295	-00090	610	-00105	251	-00162	380	-00139				
C...	205	+00080	505	+00112	089	+00161	241	+00135				
U...	285	-00060	617	-00112	250	+00166	376	-00124				
C...	225	+00102	505	+00115	084	+00161	244	+00129				
U...	327	-00090	620	-00095	245	-00160	368	-00129				
C...	237	+00108	525	+00100	085	+00161	239	+00131				
U...	345	-00095	625	-00090	246	-00146	370	-00129				
C...	250	+00112	535	+00087	100	+00149	241	+00127				
U...	362	-00097	622	-00077	249	-00137	368	-00128				
C...	265	+00102	545	+00100	112	+00139	240	+00114				
U...	377	-00063	645	-00098	251		354	-00112				
C...	314	+00120	547	+00100	Rested here 18 hours; gained by standing 00061.							
U...	434	-00079	647	-00081								
C...	355	+00083	566	+00094								
U...	438	-00072	660	-00087								
C...	366	+00079	573	+00094								
U...	445	-00060	667		Rested here 26 hours; gained by standing 00063.							
C...	385	+00073	Rested here 21 hours; gained 00021.									
U...	458	-00068										
C...	390	+00072										
U...	462	-00065										
C...	397	+00071										
U...	463											
Rested here 21 hours; resistance rose to 29488; showing gain by standing of 00020.												

Iron Wires (soft).

	No. 3.				No. 4.			
	1st Series.		2nd Series.		1st Series.		2nd Series.	
	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.	Resist- ance.	Differ- ence.
U...	34735	+00007	34995	+00094	34720	+00015	34970	+00090
C...	42	+00032	35089	+00067	35	+00043	35060	+00045
U...	74	-00002	022	+00071	78	-00006	15	+00050
C...	72	+00040	093	-00046	72	+00043	65	+00027
U...	812	-00004	047	+00054	34815	+00001	28	+00046
C...	16	+00026	101	-00059	16	+00021	74	-00044
U...	42	+00005	042	+00045	37	+00005	30	+00038
C...	47	+00015	097	-00058	42	+00018	63	-00033
U...	62	+00008	039	+00059	60	+00008	35	+00042
C...	70	+00016	008	-00050	68	+00012	77	-00045
U...	86	+00016	048	+00056	80	+00018	32	+00038
C...	902	+00012	104	-00046	98	+00022	70	+00039
U...	14	+00018	058	+00049	34920	+00010	31	+00048
C...	32	-00004	107	-00050	30	.....	79	-00037
U...	28	+00028	057	+00058	30	+00010	42	+00046
C...	56	-00036	115	-00059	40	-00010	88	-00043
U...	20	+00052	056	+00061	30	+00023	45	+00054
C...	72	-00020	117	-00055	53	-00023	99	-00030
U...	52	+00040	062	+00062	30	+00038	69	+00050
C...	92	-00028	124	-00066	68	-00028	35119	-00034
U...	64	+00051	058	+00060	40	+00024	085	+00043
C...	35015	-00033	118	-00042	64	-00019	128	-00016
U...	4982	+00059	076	+00038	45	+00020	112	+00033
C...	5041	-00039	114	-00030	65	-00015	45	-00021
U...	5002	+00056	084	+00034	40	+00035	24	+00035
C...	58	-00039	118	-00016	75	-00025	59	-00015
U...	19	+00060	102	+00040	50	+00048	44	+00036
C...	79	-00041	142	-00021	98	-00030	80	-00010
U...	38	+00058	121	+00043	68	+00046	70	+00029
C...	96	-00041	164	-00019	35014	-00026	99	-00009
U...	55		145	+00047	34988	+00062	90	+00036
C...			192	-00016	35050	-00028	35226	-00007
U...			176		32	+00056	19	+00049
C...					88	-00023	68	-00012
U...					65		56	
U...	Rested here 45 hours; loss by standing = 060.		Rested here 45 hours; gained by standing = 00029.		Rested here 21 hours; loss by standing 00095.		Rested here 21 hours; loss by standing = 00026.	

Copper Wire.

No. 4.				
1st Series.			2nd Series.	
	Resistance.	Difference.	Resistance.	Difference.
U	·17762	—·00003	·17882	—·00002
C	59	+·00019	·17880	+·00023
U	78	—·00003	·17903	+·00009
C	75	+·00013	·17894	+·00020
U	88	—·00003	·17914	—·00010
C	85	+·00012	04	+·00024
U	97	—·00003	28	+·00008
C	94	+·00014	20	+·00016
U	·17808	—·00004	36	—·00006
C	04	+·00021	30	+·00011
U	25	—·00005	41	+·00007
C	20	+·00011	34	+·00014
U	31	—·00004	48	—·00005
C	27	+·00012	43	+·00017
U	39	—·00005	60	—·00008
C	34	+·00009	52	+·00015
U	43	—·00005	67	—·00008
C	38	+·00009	59	+·00014
U	47	—·00004	73	—·00008
C	43	+·00011	65	+·00013
U	54	—·00005	78	—·00007
C	49	+·00011	71	+·00013
U	60	—·00005	84	—·00007
C	55	+·00009	77	+·00012
U	64	—·00005	89	—·00007
C	59	+·00007	82	+·00011
U	66	—·00003	93	—·00006
C	63	+·00008	87	+·00010
U	71	—·00004	97	—·00006
C	67	+·00007	91	+·00007
U	74	—·00004	98	—·00007
C	70	+·00007	91	+·00008
U	77	—·00003	99	—·00003
C	74	+·00006	96	+·00009
U	·17880		·18005	
Rested here 21 hours ; gained by standing ·00002.			Rested here 21 hours ; loss by standing ·00039.	

Zinc Wires.

	No. 5.		No. 6.	
	Resistance.	Difference.	Resistance.	Difference.
U	14063		14038	
C	077	+·00014	065	+·00027
U	095	+·00018	090	+·00025
C	104	+·00009	087	-·00003
U	128	+·00024	119	+·00032
C	135	+·00007	117	-·00002
U	146	+·00011	138	+·00021
C	149	+·00003	138	.....
U	160	+·00011	152	+·00014
C	164	+·00004	149	-·00003
U	173	+·00009	164	+·00015
C	178	+·00005	163	-·00001
U	186	+·00008	178	+·00015
C	190	+·00004	180	+·00002
U	200	+·00010	191	+·00011
C	205	+·00005	193	+·00002
U	212	+·00007	205	+·00012
C	219	+·00007	208	+·00003
U	227	+·00008	218	+·00010
C	239	+·00012	221	+·00003
U	244	+·00005	230	+·00009
C	257	+·00013	245	+·00005
U	261	+·00004	235	+·00010
C	270	+·00009	245	+·00006
U	272	+·00002	251	+·00019
C	278	+·00006	270	+·00018
U	278	.....	288	
C	295	+·00017	Wire broke.	
Wire broke.				

XLIX. *On the Distance between the Poles of a Magnet, the Coefficients of Temperature and Induction, and on the Determination of Moments of Inertia by means of Bifilar Suspension.*
By F. KOHLRAUSCH*.

WHENEVER a magnet forms the object or means of any measurement, there are especially the following properties to be taken into account. Besides its magnetic moment, the changes in the same with temperature and with the position in the magnetic field play an important part, the distribution of magnetism in the bar, and, as a first approximation, the distance apart of the poles of the magnet is of importance; and the moment of inertia of the heavy mass has to be taken into account in all the usual methods of observation.

* Translated from Weidemann's *Annalen*, Bd. xxii. p. 411.