XXVI. *Electrodynamic Qualities of Metals* (continued from Phil. Trans. Vol. 146. Read Feb. 28, 1856).—Part VI. *Effects of Stress on Magnetization.* *By* Sir William Thomson, *F.R.S. &c.*

Received and Read May 27, 1875.

178. In Parts III. and IV. of my first series of papers under this title (Transactions of the Royal Society for February 1856), I described experiments discovering effects of stress on the thermo-electric quality and the electric resistances of metals. About the time those experiments were made I also made several nugatory attempts to discover the effects of stress on magnetization; and eighteen years have passed before I have been able to resume the investigation. Early in the year 1874 I made arrangements to experiment on the magnetization of iron and steel wires in two different ways—one by observing the deflections of a suspended magnetic needle produced by the magnetization to be tested, the other by observing the throw of a galvanometer-needle, due to the momentary current induced by each sudden change of magnetism. The second method, which for brevity I shall call the ballistic method, was invented by Weber, and has been used with excellent effect by Thalén, Roland, and others. It has great advantages in respect of convenience, and the ease with which accurate results may be obtained by it; but it is not adapted to show slow changes of magnetism, and is therefore not fit for certain important parts of the investigation. On this account I am continuing arrangements for carrying out the first method, although hitherto I have obtained no good results by it.

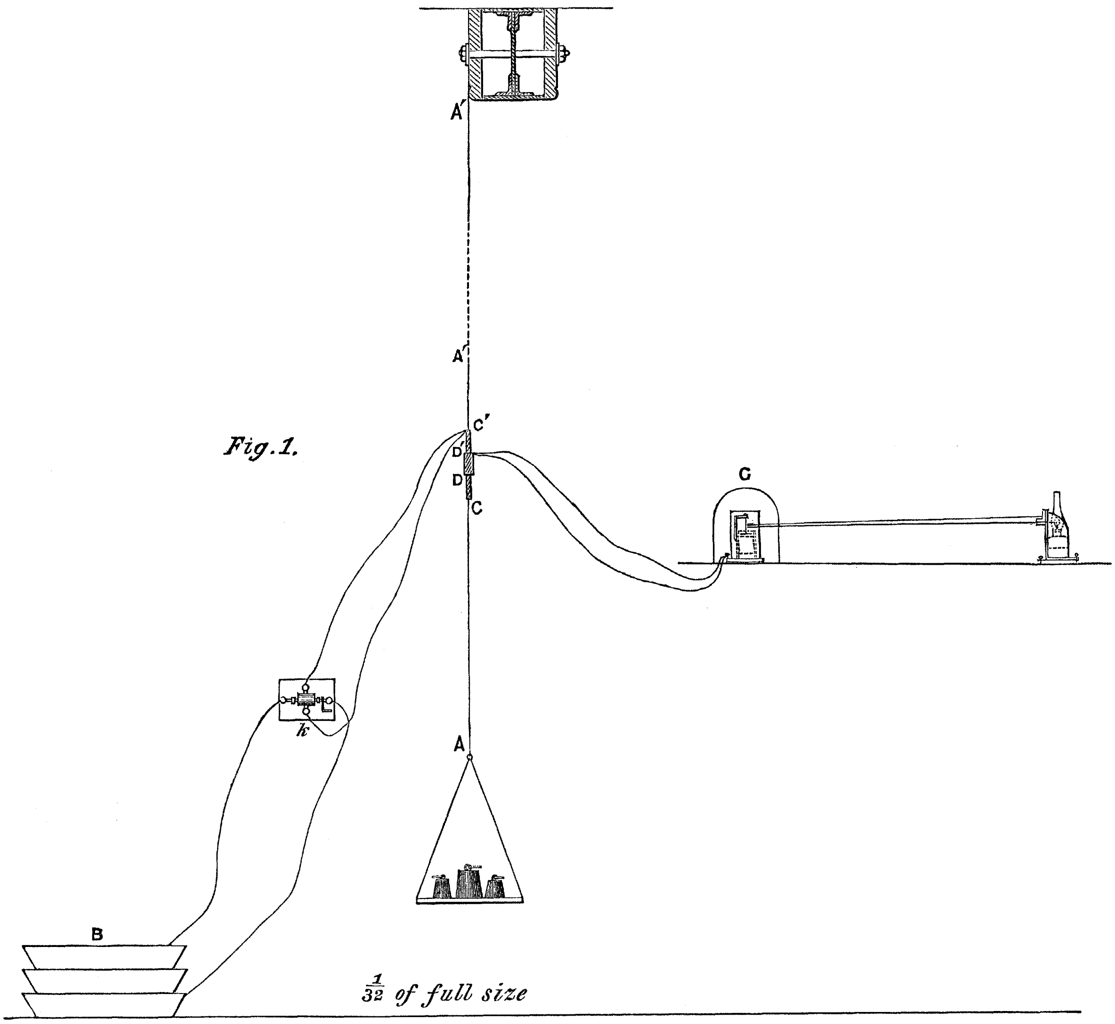
179. On the other hand, I have found the ballistic method very easy and perfectly satisfactory in every respect, except that it does not show the slow changes of magnetization. It was by it that all the results which I am now going to describe were obtained. The apparatus, which is very simple, is represented in the accompanying sketch (fig. 1).

A A′ is the wire whose magnetism is experimented on. In my first experiments it was a piece of steel pianoforte-wire, No. 22 *, Birmingham wire-gauge, that is, weighing about 3·54 grammes per metre, and therefore of ·7644 of a millimetre in diameter. It is about 5 metres long, and its upper end is firmly fixed to a beam in the ceiling of the Physical Laboratory of the University of Glasgow, where all the experiments have been made. To the lower end is attached a pan bearing weights, by means of which different amounts of pull may be rapidly applied and removed from the wire when desired. Over a portion C C′ of this wire 28·7 centimetres long there is wrapped

* This is the wire used in the American Navy and in British cable-ships for deep-sea soundings. Its strength to resist pull is such that it bears about 230 lbs. (104 kilogrammes), or the weight in air of 29·4 kilometres (or 15·9 nautical miles) of its own length.

a piece of thin sheet copper, and on the outside of that there is coiled, in two layers, 719·7 centimetres of silk-covered copper wire, the copper weighing 2·502 grammes per metre. The inner layer contains 326 turns and the outer 321. The resistance of this coil when cool is ·511 ohm. Its ends are put in communication by thick electrodes with a reversing-key, *k*, and a battery of three of my "tray" DANIELLS. The resistance of each of these cells is about ·06 of an ohm, giving for the whole battery a resistance of ·18 ohm.

Fig. 1.



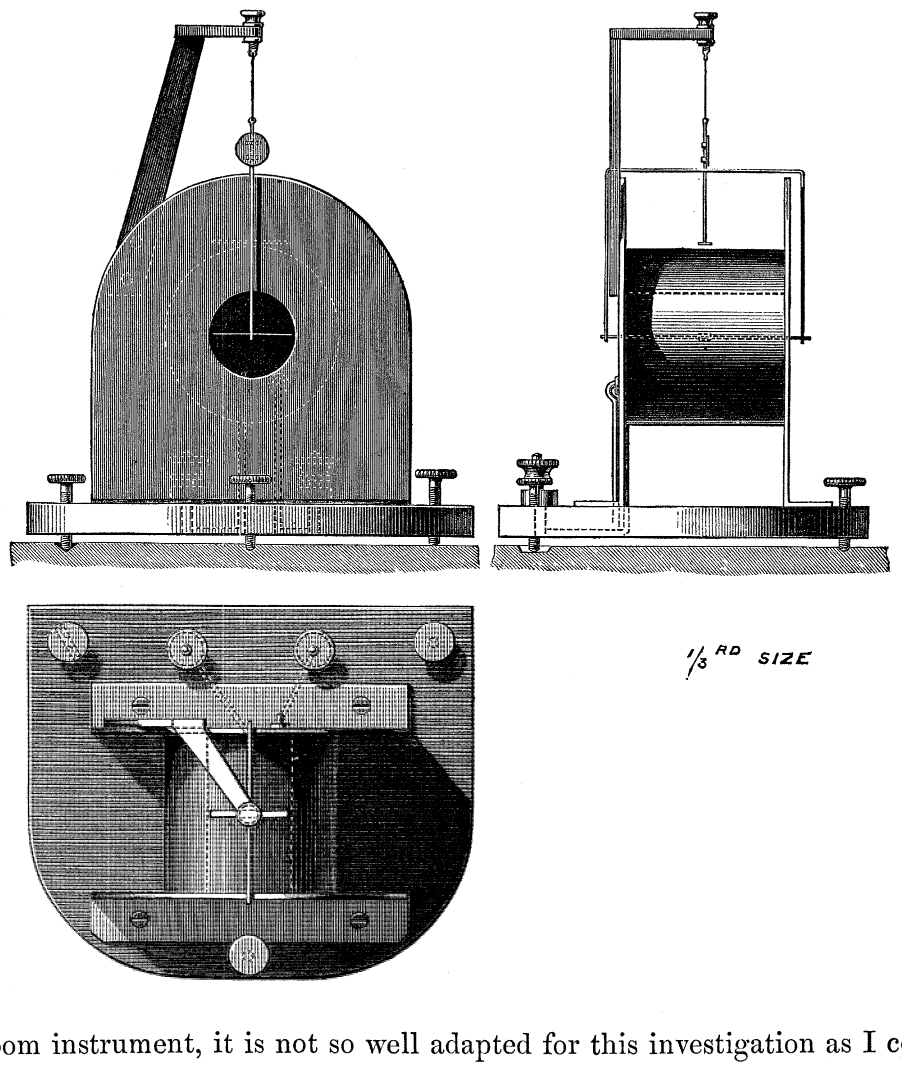
$\frac{1}{32}$ *of full size*

180. Over the coil C C′ is wound another coil D D′ 9·8 centimetres long, which contains 538 centimetres of wire, No. 26 of the Birmingham wire-gauge, with 38 centimetres for electrodes. This wire is also wound on in two layers, the inner containing 147 turns and the outer 146. The resistance of this induction-coil is 1·432 ohm, and its weight per metre 1·189 gramme.

181. The deflections of the galvanometer are read in my usual manner by the image of a fine wire fixed vertically close in front of the edge of a flat paraffine- or gas-flame. The screen on which the image is thrown is a white paper scale, divided into fortieths of an

inch, fixed at a distance of 49·8 inches from the mirror. The lamp is placed close behind the middle of the scale, and just enough below to allow its light to pass under the scale to the mirror through a small blackened tube. The galvanometer used is represented in the accompanying sketch (fig. 2). Having been extemporized from a large

Fig. 2.



lecture-room instrument, it is not so well adapted for this investigation as I could wish. It consists of an astatic pair of needles mounted on a light frame of aluminium, and carrying a light mirror placed on the frame, with its centre in the line of the suspension a little above the upper needle, and attached by means of clips, so as to admit of its being turned into and fixed in any position relatively to the frame. The resistance of the galvanometer-coil is ·634 ohm.

182. On commencing to experiment with this apparatus in March 1874, I immediately obtained some very startling and interesting results. I found that when a current was kept flowing through the magnetizing coil, and weights were alternately placed on the pan at the lower end of the wire and taken off, the effect of the pull

always diminished the magnetization, and the effect of removing the pull increased it*. The magnetizing current being then stopped, and the same operation with the weights repeated, I found similar effects—that is, the application of a pull diminished the residual magnetization, and the removal of the pull increased it. But, to my surprise, the effect was greater in this second case when merely residual magnetism was concerned than in the first case when the original magnetizing force was still in action. This greater effect in the second case was surprising, because the whole magnetization concerned in the first case was greater than the magnetization concerned in the second case by the amount of the quasi-elastic magnetization, which goes and comes again every time the magnetizing force is removed and reapplied.

183. The amount of the magnetizing force used may be roughly estimated by taking the electromotive force of each of the three cells as one volt, or 10^8 centimetre-gramme-second units. Thus, as the resistance in the circuit was about ·69 of an ohm, the strength of the current must have been about $\frac{3\times 10^8}{\cdot 69\times 10^9}$ or $\frac{1}{2\cdot 3}$. This was distributed in 647 turns of a solenoid whose axis was 28·7 centimetres long. The whole strength of current circulating round a length δx of the solenoid was therefore $\frac{647}{28\cdot 7}\times\frac{1}{2\cdot 3}\,\delta x$, and the magnetizing force to which the steel wire was subjected $4\pi\frac{647}{28\cdot 7}\times\frac{1}{2\cdot 3}$, or 123. Hence, as remarked by Professor MAXWELL, who, in reporting on this paper, first made the preceding estimate, we may call the magnetizing force a large one, so large, in fact, that it probably magnetizes the wire nearly to saturation at once. For the sake of comparison it may be remarked that the horizontal and vertical components of the earth's magnetic force at Glasgow are about ·16 and ·43; and in first experimenting with the apparatus now described, I made sure that the magnetization of the wire by the vertical component of the earth's magnetizing force was not essentially concerned in any of the results, by reversing the magnetizing current, then applying and removing weights repeatedly, then stopping the current, and again putting weights on and off repeatedly. The deflections of the galvanometer observed in this succession of operations were not sensibly different from those observed previously, but in reverse directions; that is to say, the results still fulfilled the preceding statements.

The fact that the effect of pull to diminish magnetization and of taking off pull to increase it, was found to produce a greater difference when the magnetization was solely residual than when it was sustained by the continued influence of the magnetizing force, led me to expect that the effect of making and breaking the circuit of the magnetizing coil and battery should be greater for the wire when pulled than when unpulled. Subsequent experiments proved this to be the case.

* Since the communication of this paper to the Royal Society I have found in WIEDEMANN's 'Galvanismus,' § 499, that similar results had been obtained by MATTEUCCI ('Annales de Chimie et de Physique,' 1858), and by VILLARI (POGG. 'Annalen,' 1868).—[Added May 1876.]

184. But, lastly, I found between the quasi-elastic part of the magnetization produced by alternately applying and removing the magnetizing force, and the initial reverse magnetization produced by the application of a reverse magnetizing force, a very surprising difference. The former, as stated above, is greater when the wire is pulled than when unpulled: the latter is less in the wire when pulled than when free from pull, but not by so great a difference; and the whole magnetizational effect of reversing the current suddenly must therefore be greater when the wire is pulled than when unpulled, and is found to be so.

185. The following series of experiments, I. .... XXXI., performed in November and December 1874, all on one and the same piece of steel wire, first confirmed the conclusions inferred (§ 182) from the preliminary investigation of the previous March, then reproduced with more regularity the immediate experimental results of that preliminary investigation, and lastly discovered the very remarkable phenomena described in § 184.

186. The general order of procedure followed was this. The image on the scale of the ballistic galvanometer was watched by one observer, while a second stood by to make or break circuit of magnetizing current, or put on and off weights, on word of command from the first. When the image is seen to be steady on the scale, the number at which it stands is read and recorded as "z" (zero). The order "make" or "break" or "on" or "off" is given by the first observer and executed suddenly by the second. The first observer reads and records the greatest or least number on the scale reached by the image in consequence of the electromagnetic impulse produced by the operation. Finally, the excess (positive or negative) of this reading above the immediately preceding zero is written down and marked "M" or "B," or "On" or "Off," as the case may be.

187. The connexions chanced to be so arranged that, with the direction of current invariably used in the "M's" of Series I. .... XXIX., the effect of M was to throw the image to the left, or in the direction of decreasing numbers: thus until Series XXX. a negative number always shows increase of magnetization in the direction of that produced by M. The numbers actually written down by the observers during the experiments are shown in the following extracts from their day-book, for a few of the series, chosen as examples to precede the abridged Tables of results given below for all the Series I. .... XXX.

December 2, 1874.

VIII. 112 lbs. On.			IX. 112 lbs. Off.	
Z	376		362	
M	328	−48	339	−23
Z	373		359	
B	413	+40	380	+21
Z	374		360	
M	332	−42	335	−25
Z	373		358	
B	413	+40	381	+23
Z	375		358	
M	333	−42	336	−22
Z	371		358	
B	410	+39	379	+21
Z	372		358	
M	330	−42	333	−25
Z	373		357	
B	412	+39	380	+23
Z	376		359	
M	335	−41	335	−24
Z	374		357	
B	413	+39	380	+23
Z	377		360	
M	335	−42	335	−25
Z	377		357	
B	415	+38	378	+21
Z	377		354	
M	335	−42	330	−24
Z	375		353	
B	414	+39	376	+23
Z	378		355	
M	335	−43	331	−24
Z	377		353	
B	416	+39	376	+23
Z	374		354	
M	332	−42	330	−24
Z	372		353	
B	411	+39	375	+22
Z	374		356	
M	333	−41	331	−25
Z	369		355	
B	407	+38	376	+21

December 7, 1874.

112 lbs. On and Off.

XVI. No current*.			XVII. Current flowing.	
Z	362		357	
On	404	+42	377	+20
Z	365		354	
Off	342	−23	335	−19
Z	360		352	
On	386·5	+26·5	372	+20
Z	360		352	
Off	336·5	−23·5	334	−18
Z	365		353	
On	393	+28	374	+21
Z	364		353	
Off	339	−25	335·5	−17·5
Z	362		362	
On	388	+26	380·5	+18·5
Z	365		353	
Off	340·5	−24·5	334·5	−18·5
Z	367		353	
On	391	+24	372·5	+19·5
Z	367		350	
Off	345	−22	331·5	−18·5
Z	367		357	
On	390·5	+23·5	376·5	+19·5
Z	369		360	
Off	347·5	−21·5	341	−19
Z	369		359	
On	394	+25	379	+20
Z	369		357	
Off	346	−23	331·5	−25·5
Z	370		354	
On	393	+23	373	+19
Z	370		353	
Off	347·5	−22·5	333	−20
Z	370		349	
On	392	+22	368	+19
Z	368		346	
Off	345·5	−22·5	326	−20
Z	365		346	
On	392	+27	366	+20
Z	364		342	
Off	341·5	−22·5	322	−20

* The effects here observed were diminutions and augmentations of residual magnetism from previous operations.

188. Each series from I. to XXIX. was conducted with perfect regularity on one or other of several plans, of which the details are sufficiently exemplified in the preceding unabridged quotations. Omitting now the actual readings and taking merely the differences from the zeros, we have the following full statement of results showing the amount of the electromagnetic impulse produced by each operation.

[ADDITION, May 1876.—It must not be assumed that the apparent accumulations of magnetization shown in the last columns of the Tables I. . . . . IX., or that the differences of demagnetizations and magnetizations shown at the foot of each of the Tables down to XVII., express correctly the whole changes of magnetization of the wire; for, as remarked above (§ 178), the ballistic method does not show slow changes of magnetization; and there certainly were slow changes of magnetization not shown in my ballistic experiments; because the algebraic sum of all the deflections observed day after day went on sometimes continually increasing and sometimes continually diminishing, when it was certain that there was no corresponding progressive accumulation of magnetization or of demagnetization. Some of the experiments by the method of deflection promised in § 178 were performed in last July and August, soon after the communication of this paper, and gave very remarkable results, which were free from the objection of dropping out of account slow changes of magnetization. They include effects of torsion as well as of pull. I intend to include a statement of them in a paper which I hope soon to be able to offer to the Royal Society.]

Series I. to IX.—Magnetizing Current made and broken.

November 26, 1875.—I. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	23	3	3
24	21	3	6
25	23	2	8
24	21	3	11
24	21	3	14
23	21	2	16
24	22	2	18
24	21	3	21
24	21	3	24
23	22	1	25

Series I.–IX. (continued).

November 26, 1875.—II. 28 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	22	4	4
24	22	2	6
24	26	−2	4
24	22	2	6
25	22	3	9
26	23	3	12
24	22	2	14
25	22	3	17
25	23	2	19
24	20	4	23

November 27, 1875.—III. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
24	21	3	3
24	22	2	5
24	21	3	8
24	21	3	11
22	20	2	13
24	22	2	15
24	21	3	18
23	21	2	20
24	20	4	24
23	20	3	27

November 30, 1875.—IV. 56 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
30	26	4	4
29	27	2	6
28	26	2	8
28	26	2	10
28	24	4	14
28	25	3	17
28	25	3	20
29	26	3	23
27	25	2	25
28	26	2	27

Series I.–IX. (continued).

November 30, 1875.—V. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
23	21	2	2
24	22	2	4
23	22	1	5
24	22	2	7
24	22	2	9
23	20	3	12
23	21	2	14
24	21	3	17
24	21	3	20
24	21	3	23

December 1st, 1875.—VI. 84 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
35	33	2	2
33	31	2	4
33	30	3	7
36	32	4	11
33	31	2	13
35	32	3	16
35	33	2	18
34	31	3	21
35	31	4	25
35	31	4	29

December 1, 1875.—VII. Weights off.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
26	23	3	3
26	23	3	6
25	22	3	9
26	23	3	12
26	23	3	15
26	23	3	18
25	24	1	19
26	23	3	22
26	23	3	25
26	24	2	27
25	24	1	28

Series I.–IX. (continued).

December 2, 1875.—VIII. 112 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
48	40	8	8
42	40	2	10
42	39	3	13
42	39	3	16
41	39	2	18
42	38	4	22
42	39	3	25
43	39	4	29
42	39	3	32
41	38	3	35

December 2, 1875.—IX. 112 lbs. on.

Magnetization by Make.	Decrease of Magnetization by Break.	Excess of Magnetization by Make above Demagnetization by Break.	Apparent accumulation of Magnetization.
−23	+21	−2	2
−25	+23	−2	4
−22	+21	−1	5
−25	+23	−2	7
−24	+23	−1	8
−25	+21	−4	12
−24	+23	−1	13
−24	+23	−1	14
−24	+22	−2	16
−25	+21	−4	20

Series X.–XVII.—Weights on and off.

	28 lbs.		56 lbs.	
	X. December 3. No current.	XI. December 3. Current flowing.	XII. December 4. No current.	XIII. December 5. Current flowing.
On	+5·5	+3·5	+15	+10
Off	−5	−4	−10·5	−10
On	+5	+4	+11·5	+ 9
Off	−4·5	−5	−12	− 9
On	+5·5	+5	+11	+10
Off	−5	−3·5	−11·5	− 8
On	+5	+4	+ 9·5	+ 9·5
Off	−5	−4·5	−11	− 8
On	+5	+5	+11	+ 9
Off	−5	−3·5	−10·5	− 7
On	+5·5	+3·5	+12	+10
Off	−5	−5	−10	− 7
On	+5	+3·5	+10·5	+10
Off	−4	−5·5	−10	− 9
On	+5	+4	+10	+10
Off	−5	−3·5	−10·5	− 9
On	+4·5	+4	+13·5	+ 9
Off	−4·5	−5	−10	− 9·5
On	+5	+3·5	+12	+10·5
Off	−5·5	−4·5	−11	− 9

Means of the ten 'ons' and ten 'offs.'

	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.
	5·10 demagnetization.	4·85 magnetization.	4 demagnetization.	4·4 magnetization.	11·6 demagnetization.	10·7 magnetization.	9·7 demagnetization.	8·55 magnetization.
	Excess of demagnetizations above magnetizations.		Excess of magnetizations above demagnetizations.		Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.	
	2·5		4		9		11·5	

Series X.–XVII.—Weights on and off (continued).

	84 lbs.		112 lbs.	
	XIV. December 5. No current.	XV. December 7. Current flowing.	XVI. December 7. No current.	XVII. December 7. Current flowing.
On	+28	+16	+42	+20
Off	−16	−15·5	−23	−19
On	+18	+13·5	+26·5	+20
Off	−16	−14·5	−23·5	−18
On	+18	+15·5	+28	+21
Off	−16·5	−13	−25	−17·5
On	+18	+14	+26	+18·5
Off	−18	−14	−24·5	−18·5
On	+18	+13·5	+24	+18·5
Off	−19	−15	−22	−18·5
On	+17·5	+17	+23·5	+19·5
Off	−18·5	−13·5	−21·5	−19
On	+18·5	+16	+25	+20
Off	−17	−14·5	−23	−25·5
On	+16·5	+17·5	+23	+19
Off	−18·5	−15·5	−22·5	−20
On	+18	+16	+22	+19
Off	−17·5	−14·5	−22·5	−20
On	+19	+14·5	+27	+20
Off	−16	−15·5	−22·5	−20

Means of the ten 'ons' and ten 'offs.'

	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.	Ons.	Offs.
	18·95 demagnetization.	17·3 magnetization.	15·35 demagnetization.	14·55 magnetization.	26·7 demagnetization.	23 magnetization.	19·55 demagnetization.	19·6 magnetization.
	Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.		Excess of demagnetizations above magnetizations.		Excess of magnetizations above demagnetizations.	
	16·5		8		37		5	

Series XVIII., XIX., XX.—Cycles M, On, B, Off.

	XVIII. December 8.	XIX. December 8.	XX. December 9.
	56 lbs.	84 lbs.	112 lbs.
M	−28	−27	−41
On	+ 6	+12	+20
B....................	+26	+31	+38
Off	− 7	−15	−21
M	−33	−36	−40·5
On	+ 9·5	+13	+18·5
B....................	+25	+29·5	+38·5
Off	− 7	−14	−22
M	−30	−34	−42·5
On	+ 7·5	+14·5	+18
B....................	+27	+32·5	+38·5
Off	− 8	−14	−22·5
M	−34	−35·5	−45
On	+ 9·5	+13·5	+19
B....................	+22	+29	+39·5
Off	− 8·5	−16	−21·5
M	−31	−36	−42·5
On	+10·5	+13·5	+20
B....................	+28	+30·5	+38·5
Off	− 8	−15	−21

Series XXI., XXII., XXIII.—Cycles On, M, Off, B.

	XXI. December 9.	XXII. December 9.	XXIII. December 10.
	56 lbs.	84 lbs.	112 lbs.
On	+15·5	+26	+37
M	−31	−39	−43
Off	− 9	−15	−22
B....................	+23	+24	+23·5
On	+16·5	+25·5	+37
M	−29·5	−39	−41
Off	−10	−16	−22
B....................	+22	+24	+24
On	+15·5	+26	+37·5
M	−31	−38	−42
Off	−10	−16	−21
B....................	+22	+24	+24
On	+15	+27	+36
M	−29	−39	−41
Off	−10	−16	−20·5
B....................	+21·5	+24	+23·5
On	+15·5	+26	+38
M	−28·5	−38	−42
Off	−10	−16	−21
B....................	+22	+25	+24

Series XXIV., XXV., XXVI.—Cycles M, On, Off, B.

	XXIV. December 10.	XXV. December 10.	XXVI. December 10.
	56 lbs.	84 lbs.	112 lbs.
M	−27	−25	−26
On	+10	+15	+20
Off	− 9·5	−14·5	−19·5
B................	+22	+24	+24
M	−26	−24	−25·5
On	+10·5	+14	+20
Off	− 9	−14·5	−19
B................	+21	+22	+22
M	−26	−24	−26
On	+ 9·5	+15	+20
Off	−10	−15	−20
B................	+22	+23	+21
M	−25	−26	−24
On	+ 9	+15	+20
Off	− 9	−14·5	−22
B................	+23	+24	+24
M	−25	−26	−25·5
On	+ 8	+14	+21
Off	− 9	−14·5	−23
B................	+23	+24	+25

Series XXVII., XXVIII., XXIX.

Cycles (again the same as those of XVIII., XIX., XX.) M, On, B, Off.

	XXVII. December 14.	XXVIII. December 15.	XXIX. December 16.
	56 lbs.	84 lbs.	112 lbs.
M	−30	−30	−31
On	+ 9·5	+14·5	+18·5
B................	+28·5	+34	+40
Off	− 8	−14·5	−21·5
M	−33	−39	−44
On	+ 8·5	+13·5	+18·5
B................	+29	+34·5	+40
Off	− 7	−15	−22
M	−34	−37·5	−42
On	+ 8·5	+16	+18
B................	+29·5	+34·5	+40
Off	− 8	−14	−20
M	−34	−38	−43
On	+ 9	+14	+20
B................	+28	+35	+39·5
Off	− 6·5	−14·5	−23
M	−34	−37	−42
On	+ 9	+12·5	+20
B................	+28	+34	+38
Off	− 7	−14	−19

189. Series XXX. and XXXI. were irregular. After putting on and off weights several times, and finding as before diminutions and augmentations of residual magnetism, a weight of 28 lbs. was left on the wire, and the magnetizing circuit was made with current in the same direction as before; then an additional 28 lbs. on and off: the current once more made and broken, still in same direction; then circuit made in reverse direction, and broken; lastly, 28 lbs. additional put on and taken off. The results were as follows, M(−) being now used to denote institution of current in one final direction, and M(+) in the opposite direction.

Latter part of Series XXX. December 22, 1875.—28 lbs. permanently hung on wire. "On" and "off" means another weight of 28 lbs. put on and taken off.

On + 5·5	B −25	On − 6	On + 4·5
Off − 4·5	On −10	Off + 6·5	Off − 7
M(−) − 42	Off + 5·5	On − 6	On + 5
On + 5·5	On − 6	Off + 6	Off − 5
Off − 6	Off + 6	M(−) −180	On + 4·5
B + 24·5	On − 7	On + 5	Off − 5
M(−) − 28	Off + 6·5	Off − 6·5	B +26
B + 26	On − 6	On + 5	
M(+) +181	Off + 5	Off − 4·5	

Series XXXI. December 22, 1875.—Weight of 28 lbs. hung permanently on the wire. "On" and "off" means a weight of 56 lbs. hung on in addition and taken off.

On +20	Off − 9½	M(−) and B many	M(+) +200
Off −12	B + 23½	times quickly.	M(−) −200
On +13½	M(+) +180	M(+) +184	M(+) +200
Off −12	B − 24	On. Then M(+) and	Then immediately
M(−) −40	M(−) −181	B many times quickly.	On
On + 9¼	On + 9	M(−) 155	M(−) −180
Off −10	B + 35	M(+) reading lost.	M(+) +179
B +25½	M(+) +150	M(−) −180	M(−) −179
M(−) −29	B − 35	M(+) +179½	Steel wire removed
Then immediately,	M(−) −150	Then immediately,	from core, to test
without waiting	Off − 11	without waiting for	the direct induction
for image coming	B + 25	image coming to rest,	from coil to coil.
to rest,	M(+) +182	Off	M(+) +20
B	On and M(−) and B	M(−) −199	B −19½
On +19	many times quickly.	M(+) +198	
Off −12	M(−) −34	Then immediately	
On +12	B immediately after.	On	
M(−) −40	M(+) +155	M(−) −181	
B +36	Off, and B and M(+)	M(+) +176	
M(−) −35½	and B many times	Then immediately	
Off − 10	quickly.	Off	
On + 11½	M(−) −185	M(−) −199	

190. Interpretation of Series XXX. with help from Series XXXI.—From each M($\mp$) and following B subtract and add respectively $\mp 19\frac{3}{4}$, or, say ∓ 20, for induction of coil on coil measured in last two experiments of Series XXXI. Therefore

the first M(—) of Series XXX. gave 22 of increase to the magnetization of the steel wire which had remained for six days undisturbed as left at the end of Series XXIX. After an "on" and "off" of 28 lbs.* the current was stopped, and the magnetism of the wire instantly fell 4·5. A second M(—) gave 8 of increase to the magnetization, while the current was continued, of which 6 was instantly lost when the current was stopped a minute or two after. Then M(+) without other disturbance produced 161 of demagnetization and reverse magnetization, of which 5 was lost when the current was stopped a minute or two after, and 5·5 more in the set of six ons and offs which followed. The residual reverse magnetization must (as we may judge from subsequent results of Series XXX. and XXXI.) have been approximately equal to the immediately previous residual magnetization remaining from all the previous M(—) and other operations to which the wire had been subjected from the time in November when it was set up for the experiments. Subtracting $10\frac{1}{2}$ from 161 we find $150\frac{1}{2}$ for the number measuring the change from the previous (—) magnetization to the equal (+) magnetization in the wire at the present stage of its history. The amount of this magnetization is therefore $75\frac{1}{4}$, say 75. With this amount of magnetization in the wire, and 28 lbs. hanging constantly on it, the effect of putting on and off another 28 lbs. is to diminish and increase the magnetism by 6; that is to say, to diminish it and increase it by about $\frac{1}{12}$ of its mean value (which, according to these rough estimates, is 73 of our arbitrary scale). The remainder of Series XXX. speaks intelligibly for itself.

191. Interpretation of Series XXXI.—The first on gave a diminution 20 in the magnetization, the second $13\frac{1}{2}$; the first on and the off, on, off following, gave on the whole a diminution of $9\frac{1}{2}$, that is to say, shook out $9\frac{1}{2}$ of the 75 of the residual magnetism remaining from Series XXX. The effect of repeated ons and offs on the $65\frac{1}{2}$ of remaining magnetism would no doubt have shaken but very little more out, and would have caused alternate diminutions and augmentations of about 12; that is to say, with 56 lbs. hung on, in addition to the constant 28 lbs., the magnetization of the wire would have been 53, and with only the 28 lbs. it would have been 65.

The M(—), on, off, and B which actually followed, added $15\frac{1}{4}$ to the magnetization, and so brought it up to about $80\frac{3}{4}$, or $5\frac{3}{4}$ more than it had at the beginning of Series XXXI. The subsequent M(—) and B probably produced little, if any, further change in the residual magnetization; and the on, off, on which followed confirmed the previous result of augmentation 12 and diminution 12, alternately by off and on, after something considerable shaken out permanently by the first on. The off, on, off after M(—) with current still flowing gave about 10 instead of the 12 found previously when the current was not flowing. These results agree in kind and amount with what was to be expected from Series XIV. and XV., considering that "on" and "off" in those series was 84 lbs. on and off (with nothing, or only a very slight steadying weight kept always on), whereas now the "on" and "off" means change from 28 lbs. to 84 lbs. and back.

192. Interpretation of Series XXXI. continued.—Taking now the effects of Ms and

* Another weight of 28 lbs. hanging constantly on the wire.

Bs, and (§ 191) subtracting 20 from each number, we see that the effect on the magnetization of the wire producible by repeating M(−) and B over and over again without other disturbance would be about 16 each way with 84 lbs. on, and probably between $5\frac{1}{2}$ and 9 with 28 lbs. on. (This agrees in kind with the conclusion deducible from the comparison between the previous Series II. and VI.; but the absolute magnitudes of the results seem smaller, probably because of less battery-power in those series than in Series XXXI.) The whole effects of the M(+) after M(−) and B, and of the M(−) after M(+) and B, were still, as in Series XXX., each equal to 180 or 181, with only the 28 lbs. on, and therefore (subtracting 20 for the induction from coil to coil) we had 160 or 161, say $160\frac{1}{2}$, for the sum of the demagnetization and reverse magnetization produced by a M following a B and a previous M of the opposite direction. Now came, in the course of a few minutes, a most startling discovery. With the 84 lbs. on, the sum of magnetization and demagnetization produced by the M after B from previous opposite M was 130, or less by $30\frac{1}{2}$ with those than with the 28 lbs. Thus we see that while the magnetic effect of stopping the current is *greater*, the effect of subsequently instituting the current in the reverse direction is *less*, with the heavy than with the light weight; and less by about three times as great a difference.

193. Consider, lastly, the effect of a sudden reversal of the current. This may be regarded as the sum of the effects of stopping it, and starting it in the reverse direction; and therefore may be expected to be less with the 84 lbs. than with the 28 lbs. by about $\frac{2}{3}$ of the difference between the effects of starting the reverse current with the heavy and with the light weights hung on the wire. This inference is verified in the concluding thirteen results of the series before removal of the steel wire. Thus (§ 190) subtracting 40 for the induction of coil on coil in the reversal, we find 140, $139\frac{1}{2}$, 141, 136, 140, 139, 139 for magnetic effects of reversals with 84 lbs. hung on the wire, of which the mean is 139·2; and 159, 158, 159, 160, 160, 160, for the magnetic effects of reversals with 28 lbs. on, of which the mean is 159·3.

194. After the conclusion of these experiments on the steel wire, I made many experiments of the same kind on soft-iron wires of various qualities substituted for it in the same apparatus, and I have obtained results of the same kind, as to the effects of hanging on and taking off weights, while the magnetizing current is kept flowing. I have also obtained some very remarkable and perplexing results by putting weights on and off with the current not flowing. In one of the iron wires the effect found was opposite to that in steel; that is to say, putting on weight augmented and taking off weight diminished the residual magnetism; in another the same effect as in steel was found, that is, putting on diminished and taking off augmented the residual magnetism. Neither of these was as soft as some of the other wires tried, and the one ("bright soft iron wire," JOHNSTONE'S) that agreed with steel was remarked on at the time as *much harder* than another that had been previously experimented on ("black soft iron wire," JOHNSTONE'S). This latter seemed utterly destitute of retentive power under the influence of putting the weights on and off. Like all the others it always experienced a diminution

of magnetism by weights on and increase by weights off, when the magnetizing current was flowing. But when the current was stopped large effects (larger than those when the current was flowing) were produced by putting on and taking off the weights; and these effects were always of the same kind, whichever had been the direction of the current.

195. I have not yet been able to explain these effects by terrestrial magnetic force*, nor to even guess any other possible cause; and have in fact, since the 23rd of December last, been exceedingly perplexed by seeming anomalies which the various soft-iron wires tried have presented, commencing that day with a reversal of the electromagnetic effect of the "off" and "on" which the first of the wires experimented on showed after the magnetizing current had been made for the first time and broken, and a weight of 14 lbs. put on and off several times had first shaken out nearly one third of the residual magnetism, and then given alternate augmentation by "on" and diminution by "off" of the magnetism that remained. A weight of 28 lbs. was then hung on, and it stretched the wire permanently by about 8 per cent. of its length. Then immediately I found reverse effects by putting off and on and off the 28 lbs., and on and off smaller weights—the "on" giving diminution and the "off" augmentation of what would have been the residual magnetism, if residual magnetism there was, from the first magnetization by the current. This quality remained until an hour or two later, when the current was once more made in the same direction as the first, and broken again. Then 14 lbs. put on actually gave augmentation of the residual magnetism (instead of shaking out a considerable quantity as the first "on" after the first "B" had done), and the offs, ons, and offs following gave alternate diminution (by the offs) and augmentation (by the ons); that is to say, the effects were the *same in kind* as the effects which had been observed before the stretching by the 28 lbs.; but they were nearly three times as great in amount as they had been then, with the same weight of 14 lbs. on and off. Thenceforth the same piece of wire (experimented on several more days up till Jan. 12, 1875) and other pieces of similar wire tried after it, with the current made sometimes in one direction and sometimes in the other, and broken, and different amounts of weight up to 28 lbs. put on and off, always showed increase of the residual magnetism by the "on" and diminution by the "off." Even the first "on" after the stoppage of the current gave always an increase of the magnetism; but when the weight was as much as 28 lbs. the "shaking out" tendency was remarkably shown by the increase by the first "on" being much less than the diminution by the first "off."

196. The soft-iron wire experimented on on the 23rd of December gave, with 28 lbs. hanging on it, smaller effects of successive "makes," in one direction, and breaks of the current; a greater effect when it was made in the reverse direction; and a smaller sum

* [Note added January 1877.—Nearly six months later I ascertained that these startlingly great effects actually were due to the vertical component of the earth's force, though this was only about $\frac{1}{300}$ of the magnetizing force of the currents used.]

of these two effects (that is to say, a smaller effect) on the reversal of the current than when it was un-pulled.

197. The investigation is being continued with special arrangements to discover the explanation of the seeming anomalies described above, and with the further object of determining in absolute measure the amounts of all the ascertained effects, at different temperatures up to 100° Cent. It is needless to give in the mean time any minute details of the experiments already made on the soft-iron wires by which the results now described were obtained.

ABSTRACT OF THE PRECEDING PAPER.

WEBER's method, by aid of electromagnetic induction and a "ballistic galvanometer" to measure it, which has been practised with so much success by THALÉN, ROLAND, and others, has been used in the investigation of which the results are at present communicated; but partial trials have been made by the direct magnetometric method (deflections of a needle), and this method is kept in view for testing slow changes of magnetization which the electromagnetic method fails to detect.

The metals experimented on have been steel pianoforte-wire, of the kind used for deep-sea soundings by the American Navy and British cable-ships; and soft-iron wires of about the same gauge, but of several different qualities.

I. *Steel.*

The steel wire weighs about 14½ lbs. per nautical mile, and bears 230 lbs. Weights of from 28 lbs. to 112 lbs. were hung on it and taken off, and results described shortly as follows were found:—

(1) The magnetization is diminished by hanging on weights, and increased by taking the weights off, when the magnetizing current is kept flowing.

(2) The residual magnetism remaining after the current is stopped is also diminished by hanging on the weights, and increased by taking them off.

(3) The absolute amount of the difference of magnetization produced by putting on or taking off weights is greater with the mere residual magnetism when the current is stopped than with the whole magnetism when the magnetizing current is kept flowing.

(4) The changes of magnetization produced by making the magnetizing current always in one direction and stopping it are greater with the weights on than off.

(5) After the magnetizing current has been made in either direction and stopped, the effect of making it in the reverse direction is less with the weights on than off.

(6) The difference announced in (5) is a much greater difference than that in the opposite direction between the effects of stopping the current with weights on and weights off, announced in (4).

(7) When the current is suddenly reversed, the magnetic effect is less with the weights on than with the weights off.

II. *Soft-Iron Wires.*

Wires of about the same gauge as the steel were used, but, except one of them, bore only about 28 lbs. instead of 230. All of three or four kinds tried agreed with the steel in (1).

The first tried behaved (except a seeming anomaly, hitherto unexplained) in the reverse manner to steel in respect to (2), (4), (5), and (6); it agreed with the steel in respect to (7). Another iron wire*, which, though called "soft," was much less soft than the first, agreed with steel in respect to (1) and (2), but [differing from steel in respect to (3)] showed greater effects of weights on and off when the magnetizing current was flowing than when it was stopped.

Other soft-iron wires which were very soft, softer even than the first, agreed with all the steel and iron wires in respect to (1), but gave results when tested for (2) which proved an exceedingly transient character of the residual magnetism, and were otherwise seemingly anomalous.

The investigation is being continued with special arrangements to find the explanation of these apparent anomalies, and with the further object of ascertaining in absolute measure the amounts of all the proved effects at different temperatures up to 100° Cent.

[POSTSCRIPT, Jan. 1877.—The proposed continuation of the investigation is still going on. A part of it (of which an abstract, communicated to the Royal Society at its next ordinary meeting after the communication of the preceding paper, has been published in the 'Proceedings' for June 1875) completely explains the "seeming anomalies" of §§ 194, 195, above.]

* It was tested magnetically with weights up to 56 lbs., and broke, unfairly however, when 63 lbs. were hung on.