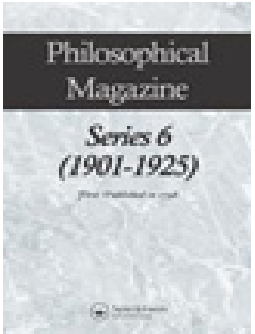

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JUNE 1901.

LX. *The Magnetic Properties of the Alloys of Cast-Iron and Aluminium.*—Part II.

By S. W. Richardson, *D.Sc., Principal and Professor of Physics at the Hartley College, Southampton, and* Louis Lownds, *B.Sc.*, 1851 *Exhibition Research Scholar, University College, Nottingham*[*].

[Plate VI.]

Contents.

§ I. *Introduction.*

An account of a series of experiments performed by one of us on the magnetic properties of certain impure alloys of iron and aluminium is given in the Philosophical Magazine for January 1900. As the results obtained from these experiments were of a very interesting character, the authors

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[*] Communicated by the Physical Society: read June 8, 1900.

thought it desirable to undertake further experiments on the magnetic behaviour of these specimens.

Experiments were accordingly made in the first instance to ascertain in what way the hysteresis-loss, between given limits of the field strength, was connected with the temperature for the specimen containing 3·64 per cent. of aluminium.

As will be seen later, these experiments show that the hysteresis-loss attains a maximum value at a temperature considerably higher than the temperature of maximum induction

An account is also given of some experiments on the changes produced in the magnetic properties of the alloy by heating to a high temperature and subsequently cooling. It is shown that the magnetic properties depend largely on the previous history of the specimen; successive curves connecting the maximum induction obtained for any given value of the field-strength and the temperature differing from one another to some extent when the heating has been carried to a high temperature. This difference has been found to be greater for weak than for strong fields.

There does not, however, appear to be any essential difference between the behaviour of this alloy during heating and cooling (except near the *temperature of minimum permeability*, *e. g.* critical temperature).

Similar results have been obtained for the specimen containing 5·44 per cent. of aluminium. For the specimen containing 9·89 per cent. of aluminium, however, no change in the magnetic properties could be detected due to heating and cooling unless the heating was continued to about 670° C., which temperature is about 220° higher than the temperature of minimum permeability for this specimen (*e.g.* 450° C.). In addition an account is given of some experiments on the abrupt change in the permeability that takes place at a temperature of 652° C. (*vide* p. 139, Phil. Mag. Jan. 1900).

The Ballistic method was used for determining the hysteresis-loss; and the Balance method (*vide* Part I.) for obtaining the smaller values of the induction when the specimen was near the temperature of *minimum permeability.*

The specimen in the form of a ring was wrapped round with asbestos-paper. Next to this was twisted the thermometer-wire which consisted of platinum wire of ·2 millim. diameter. This wire was connected to platinum leads of ·5 millim. diameter.

Compensating leads, cut from the same specimen of wire, passed out along with these between the primary and secondary winds.

The primary and secondary coils, which were of copper wire and insulated with asbestos-paper, came next, and externally a well-insulated platinum wire (diam. ·5 millim.) was wound non-inductively round the ring.

The specimen was heated electrically, this non-inductively wound platinum wire being used as a heating circuit. The specimen, with the surrounding coils, was packed in asbestos waste and placed in a sand-bath. Experiments were made at temperatures ranging from 15° C. to 800° C.

The conclusions arrived at from these experiments are as follows :—

(1) The hysteresis-loss at first diminishes as the temperature rises. It then increases and reaches a maximum value at about 550° C., which temperature is about 80° higher than the temperature of maximum induction. On further heating it falls off rapidly and becomes negligible at about 700° C.

(2) The magnetic properties of the specimen depend largely on its previous history.

(3) There is no essential difference between the behaviour of this specimen during heating and cooling* (except near the temperature of minimum permeability).

(4) An abrupt increase in the permeability takes place at 652° C. (during heating) followed by an equally abrupt diminution on further heating.

(5) This abrupt change in the permeability is more marked with falling than with rising temperatures.

(6) Continued heating and cooling diminish the permeability of this specimen (probably due to disintegration)*.

(7) The curve connecting the temperature of minimum permeability and the percentage of aluminium for the specimens investigated is a straight line.

(8) The microscopic examination of the specimens shows the presence of crystals.

§ II. *The Magnetic Measurements.*

The first series of experiments was made with a view to ascertaining in what way the hysteresis-loss between given limits of the field-strength was connected with the temperature of the specimen. The ballistic method of measuring the induction was made use of in this set of experiments.

The experimental arrangement was roughly as follows :—

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* This statement does not hold for specimens containing only a small quantity of impurity, as will be shown in a subsequent communication.

The secondary of the ring was joined up in series with the secondary of a standard mutual inductance-coil and a D'Arsonval ballistic galvanometer.

A known standardizing current was then sent through the primary of the mutual inductance-coil and the throw of a spot of light (reflected from the mirror of the galvanometer on to a transparent scale) on reversing the current was noted.

Then if

M = the value in c.g.s. units of the standard mutual inductance ;
γ = the value of the standardizing current ;
d = the throw of the spot of light ;
k = some constant ;

we have

$$M\gamma = kd$$

or

$$k = \frac{M\gamma}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The primary of the standard mutual inductance-coil was then disconnected, and a current was sent through the primary of the ring and an adjustable resistance. This current was then varied 'by steps,' and the throw corresponding to any change $\delta\gamma$ in the current strength was noted.

Then if

N = the number of turns in the secondary of the ring ;
S = the mean sectional area of the ring ;
δB = the change in the induction in the ring corresponding to a change $\delta\gamma$ in the current strength ;
d' = the throw of the spot of light ;

we have

$$\delta B \,.\, S \,.\, N = kd'$$

or

$$\delta B = k\frac{d'}{SN} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Combining (1) and (2) we obtain the equation

$$\delta B = \frac{M \,.\, \gamma}{d} \,.\, \frac{d'}{S \,.\, N}.$$

The Primary Circuit.

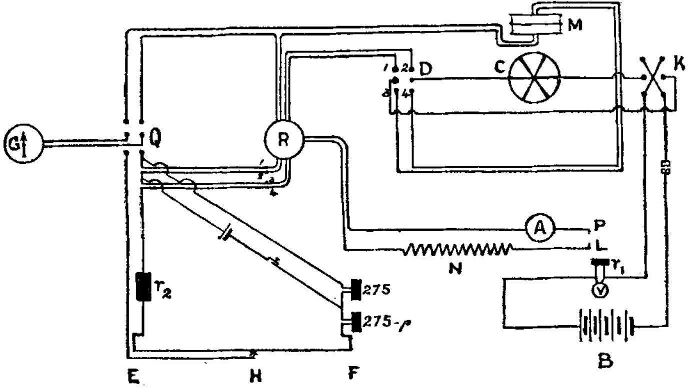
The ring was wound with a primary coil of 42 turns of copper wire insulated with asbestos-paper.

The primary was connected to the two mercury cups 1 & 2 of the rocker D (*vide* fig. 1).

To the cups 3 & 4 of this rocker were connected the terminals of the primary of the mutual inductance-coil M.

This rocker enabled the battery B to be connected at will to either the primary of the ring R or the primary of the standard mutual inductance-coil M.

Fig. 1.



The rocker D was directly connected to a variable resistance C and a reversing-key K.

To K was connected a battery of five storage-cells B and a Weston's voltmeter V, to the terminals of which was attached a resistance r_1.

The value of this resistance was one ohm, and hence the reading of the voltmeter in volts was numerically equal to the primary current in amperes.

This resistance was composed of thick platinoid wire twisted spirally and suspended by threads in a box with perforated sides and cover to allow the free circulation of air round the wire.

It was found by trial that the resistance of this coil was not appreciably changed by the passage of the greatest current used in the experiments.

The adjustable resistance C consisted of a number of coils of platinoid wire attached to a brass frame. The free ends of these coils were connected to a series of stops on the upper circle. Contact was made by means of a T-shaped brass arm revolving round the axis of the frame, and of such dimensions as to enable the resistance to be varied without breaking the circuit. This arrangement of coils was found very convenient for varying the current 'by steps.'

The Secondary Circuit.

The secondary of the ring and the secondary of the mutual inductance-coil were connected permanently to one another throughout the experiments. This circuit could be connected when desired to the galvanometer terminals by means of the rocker Q.

The galvanometer was a Crompton Midget D'Arsonval, and was suitable for ballistic or deflective zero work.

This instrument consists of a circular coil suspended bifilarly between the poles of a permanent magnet. The suspending fibres, which are of bronze, serve to carry the current. The galvanometer was very dead-beat and consequently the throws could be read with considerable ease.

The secondary circuit was kept closed throughout a series of readings, and the throws were always taken in the same direction. The kind of accuracy obtainable with this instrument can be seen from the following observations. The primary of the standard mutual inductance-coil was connected to the battery, and three successive readings of the kick obtained on reversing the current in the primary were taken for currents of different strengths.

The following set of readings were obtained :—

Current in Amperes.	Throws.				Throw ÷ current.
	1.	2.	3.	Mean.	
1·42	152	149	151	150·7	106·1
1·075	114·5	113	115	114·2	106·2
0·782	83	83	82·5	82·8	105·9
C·27	28·5	29	28·5	28·7	106·3

It will be seen from this table that the instrument is suitable for ballistic work.

The value of the standard mutual inductance-coil was 533,626 C.G.S. units. Its value was obtained by Mr. C. G. Lamb by comparison with a standard coil kept in the Engineering Laboratory at Cambridge.

§ III. *The Measurement of Temperature.*

The method used for measuring the resistance of the thermometer-wire was the same, in all essentials, as that described in Part I. (Phil. Mag. Jan. 1900). The four arms of the bridge consisted of

(1) The thermometer-wire and leads.
(2) The compensating leads, a resistance r_2, and a portion of the bridge-wire EH.
(3) A resistance of 275 ohms.
(4) A resistance of $(275-\rho)$ ohms + portion of bridge-wire HF.

[ρ being equal to the resistance of HF to within $\frac{1}{20}$ of an ohm.]

When a balance is obtained, the resistance r_t of the thermometer-wire is given by

$$r_t = r_2 + \text{resistance of E H.}$$

The temperature was deduced from r_t by means of the formula

$$t = 100\,\frac{r_t - r_0}{r_{100} - r_0} + \delta\left\{\left(\frac{t}{100}\right) - \frac{t}{100}\right\}.$$

The values of r_0, r_{100}, and δ for the given specimen of wire were determined from observations of its resistance in ice, steam, and the vapour of boiling sulphur.

This specimen of wire was obtained from Johnson & Matthey, and was of the quality prepared by this firm for thermometer work.

For this wire $\delta = 1{\cdot}57$

and $r_{100} = r_0(1 + 0{\cdot}377)$.

§ IV. *The Heating Circuit.*

The heating circuit consisted of a platinum wire, of diameter 0·5 mm., well insulated with asbestos-paper, and wound non-inductively round the ring outside the other coils. This wire was connected with an ammeter A (*vide* fig. 1), an adjustable resistance N of thick platinoid wire, and the terminals of the town mains (100 volts) P, L. By altering the value of the resistance N the heating current could be varied at will, and thus any required temperature (within the limits of the experiments) could be obtained.

With this arrangement a current of 7 amperes raised the temperature of the ring above 800° C.

The insulation resistance between the various coils was tested from time to time during the experiments. In no case (after the first heating) was it less than 1,000,000 ohms, and in general it probably was much greater than this.

§ V. *Connexion between Hysteresis Loss and Temperature.*

It had been observed in the earlier experiments that the curve connecting the maximum induction reached at each reversal and the temperature for a given value of the field-strength altered to some extent after the specimen had been heated to a high temperature. This was also found to be the case with the specimen containing 5·44 per cent. of aluminium. In the case of the other two specimens investigated, however (the one containing 9·89 and the other 18·47 per cent. of aluminium), this was not the case, unless the temperature reached was much higher than the temperature of minimum permeability.

For the alloy containing 9·89 per cent. of aluminium the curve was quite constant under all conditions, unless the specimen was raised to a temperature of 670° C. (*i. e.* 220° above the temperature of minimum permeability), in which case a new curve of the same general shape as the original curve was obtained.

The change in this case may be due to the specimen reaching the melting-point of aluminium. That conclusion, however, is not borne out by the experiments on other specimens, as in general a noticeable change takes place at a temperature considerably lower than this.

In order to obtain comparable results, the loops were taken in the order of increasing temperature: the temperature on any day on which an experiment was made being higher than that reached in the preceding experiment.

The experiments were conducted under the following conditions:—

At about 10 A.M. the heating current necessary to produce the required temperature was started in the heating circuit.

A steady temperature was, in general, reached at about 3 P.M.

The specimen was kept at this temperature till about 5 P.M., to ensure a uniformity of temperature when a loop was taken.

The specimen was then allowed to cool, and the process of re-heating was commenced on the following day[*].

In some cases several loops were taken in one day. When this was so, the higher temperatures were obtained without first cooling the specimen to the temperature of the room.

The standardising throw was taken before and after the observations for each hysteresis-loop.

The loops obtained are shown on Plate VI.

[*] This method is spoken of as the method of *successive heatings*.

Data.

Temp. 24° C.		Temp. 159° C.		Temp. 226° C.		Temp. 311° C.	
H. c.g.s. units.	B. lines per sq. cm.	H. c.g.s. units.	B. lines per sq. cm.	H. c.g.s. units.	B. lines per sq. cm.	H. c.g.s. units.	B. lines per sq. cm.
8·20	3089	8·20	3108	8·20	3147	8·20	3309
6·64	2956	6·64	2956	6·64	2994	6·64	3156
4·81	2765	4·81	2727	4·81	2784	4·81	2927
3·36	2575	3·36	2517	3·36	2574	3·36	2736
2·18	2365	2·18	2327	2·18	2546	2·18	2526
1·06	2155	1·06	2098	1·06	2098	1·06	2260
·47	2021	·47	1964	·47	1983	·47	2107
0	1850	0	1793	0	1812	0	1936
− ·47	1754	− ·47	1659	− ·47	1678	− ·47	1764
−1·06	1487	−1·06	1392	−1·06	1374	−1·06	1402
−2·18	648	−2·18	362	−2·18	133	−2·18	− 372
−3·33	− 820	−3·36	−1125	−3·36	−1363	−3·36	−1783
−4·81	−1983	−4·81	−2117	−4·81	−2250	−4·81	−2507
−6·64	−2708	−6·64	−2746	−6·64	−2822	−6·64	−3022
−8·20	−3089	−8·20	−3108	−8·20	−3147	−8·20	−3309
July 21.		July 21.		July 24.		July 25.	

Temp. 361° C.		Temp. 370° C.		Temp. 381° C.		Temp. 392° C.	
H.	B.	H.	B.	H.	B.	H.	B.
8·20	3318	8·20	3318	8·20	3213	8·20	2890
6·64	3185	6·64	3185	6·64	3080	6·64	2772
4·81	2994	4·81	2975	4·81	2889	4·81	2595
3·36	2784	3·36	2765	3·36	2698	3·36	2418
2·18	2555	2·18	2498	2·18	2470	2·18	2241
1·06	2307	1·06	2288	1·06	2241	1·06	2005
·47	2155	·47	2136	·47	2088	·47	1868
0	1926	0	1983	0	1878	0	1691
− ·47	1812	− ·47	1793	− ·47	1745	− ·47	1514
−1·06	1392	−1·06	1373	−1·06	1306	−1·06	1081
−2·18	− 839	−2·18	− 972	−2·18	−1020	−2·18	− 983
−3·36	−2040	−3·36	−2136	−3·36	−2069	−3·36	−1868
−4·81	−2651	−4·81	−2689	−4·81	−2603	−4·81	−2339
−6·64	−3070	−6·64	−3070	−6·64	−2984	−6·64	−2693
−8·20	−3318	−8·20	−3318	−8·20	−3213	−8·20	−2890
July 26. Insulation tested. R > 10^6 ohms.		July 26.		July 26.		July 28.	

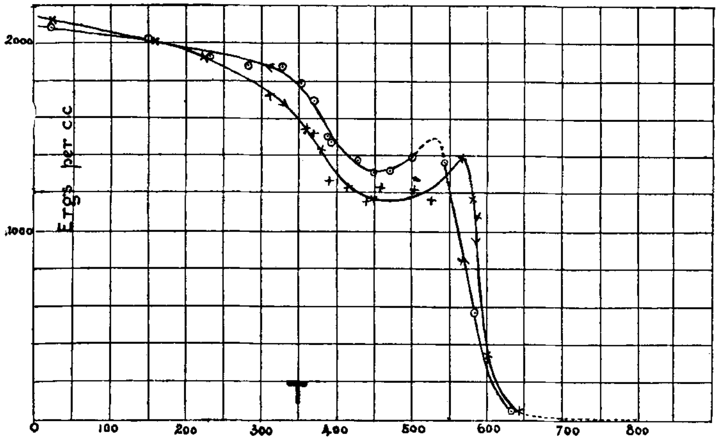
Data.

Temp. 416° C.		Temp. 449° C.		Temp. 460° C.		Temp. 502° C.	
H.	B.	H.	B.	H.	B.	H.	B.
8·20	2625	8·20	2487	8·20	2389	8·20	2239
6·64	2507	6·64	2398	6·64	2301	6·64	2151
4·81	2349	4·81	2257	4·81	2177	4·81	2027
3·36	2212	3·36	2124	3·36	2053	3·36	1903
2·18	2074	2·18	1991	2·18	1929	2·18	1797
1·06	1897	1·06	1832	1·06	1770	1·06	1673
·47	1779	·47	1726	·47	1681	·47	1602
0	1602	0	1584	0	1487	0	1478
− ·47	1524	− ·47	1460	− ·47	1451	− ·47	1407
−1·06	1150	1·06	1106	−1·06	1168	−1·06	1195
−2·18	− 875	−2·18	− 858	−2·18	− 584	−2·18	− 292
−3·36	−1701	−3·36	−1637	−3·36	−1487	−3·36	−1319
−4·81	−2133	−4·81	−2044	−4·81	−1912	−4·81	−1779
−6·64	−2448	−6·64	−2328	−6·64	−2212	−6·64	−2080
−8·20	−2625	−8·20	−2487	−8·20	−2389	−8·20	−2239
July 28.		Aug. 15. Insulation tested. R > 10^6 ohms.		Aug. 18.		Aug. 16. Insulation tested. R > 10^6 ohms.	

Temp. 569° C.		Temp. 582° C.		Temp. 602° C.		Temp. 642° C.	
H.	B.	H.	B.	H.	B.	H.	B.
8·20	1690	8·20	1354	8·20	637	8·20	221
6·64	1620	6·64	1301	6·70	584	6·64	203
4·81	1513	4·81	1212	4·93	513	4·81	168
3·36	1425	3·36	1124	3·45	460	3·36	142
2·18	1319	2·18	1053	2·30	389	2·18	124
1·06	1230	1·06	965	1·12	336	1·06	97
·47	1177	·47	912	·53	301	·47	80
0	1106	0	841	0	283	0	62
− ·47	1053	− ·47	788	− ·53	230	− ·47	44
−1·06	929	−1·06	664	−1·12	159	−1·06	9
−2·18	593	−2·18	398	−2·30	− 18	−2·18	− 62
−3·36	− 27	−3·36	80	−3·45	−159	−3·36	−115
−4·81	− 929	−4·81	− 558	−4·93	−336	−4·81	−150
−6·64	−1460	−6·64	−1124	−6·70	−513	−6·64	−186
−8·20	−1690	−8·20	−1354	−8·20	−637	−8·20	−221
Aug. 18. Insulation tested. R > 10^6 ohms.		Aug. 24.		Aug. 25.		Aug. 30. Insulation tested. R > 10^6 ohms.	

It has been stated that the B and T curves (H = a constant) change to some extent after the specimen has been raised to a high temperature. It was hence thought desirable to obtain a set of hysteresis-loops while the alloy cooled, to see whether there was any essential difference between its behaviour during the processes of heating and cooling.

Fig. 2.



Accordingly the specimen was heated to 800° C., and allowed to cool by stages down to the temperature of the room.

Double reversal throws and loops were taken at intervals when the temperature was steady.

This series of experiments lasted 26 hours, both the authors being present throughout the experiments.

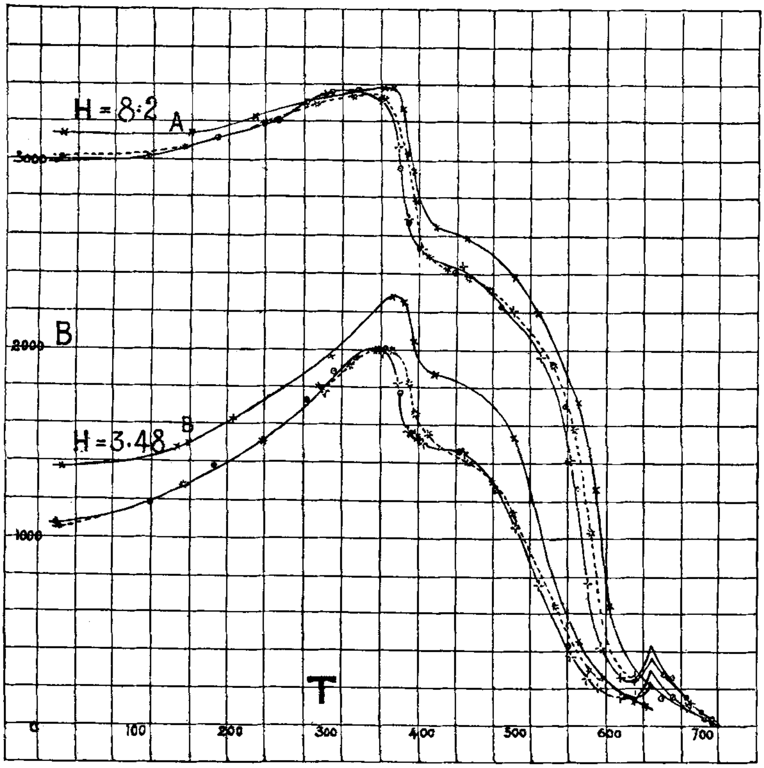
The curves of double reversals will be seen to be different from those obtained by successive heatings (*vide* fig. 3), though, as will be seen later, the curves obtained from consecutive heatings and coolings approximate much more nearly to one another.

As a check on the results, the ring was unwound and then re-wound with cotton-covered copper wire soaked in melted paraffin, and again tested. The values obtained in the two cases were found to confirm one another.

The loops obtained are shown on Plate VI.

The hysteresis loss was calculated in each case and curves connecting the hysteresis loss and the temperature for the given limits of field-strength are shown as fig. 2.

Fig. 3.



Data.

H.	583° C.	544° C.	501° C.	471° C.	454° C.	428° C.
	B.	B.	B.	B.	B.	B.
8·20	982	1757	2084	2204	2257	2336
6·90	912	1686	2013	2133	2186	2265
5·25	823	1615	1925	2027	2080	2159
3·84	735	1527	1828	1912	1956	2044
2·60	646	1403	1686	1788	1832	1885
1·33	540	1314	1580	1646	1681	1743
·59	487	1252	1492	1558	1584	1637
0	451	1102	1358	1425	1460	1469
−·59	345	1075	1261	1327	1345	1389
−1·33	204	872	1013	1080	1071	1089
−2·60	−62	243	− 173	− 434	− 540	− 593
−3·84	−239	− 642	−1181	−1372	−1460	−1496
−5·25	−469	−1226	−1659	−1797	−1867	−1920
−6·90	−770	−1590	−1943	−2062	−2115	−2186
−8·20	−982	−1757	−2084	−2204	−2257	−2236

Data.

H.	394° C.	388° C.	370° C.	354° C.	330° C.	234° C.
	B.	B.	B.	B.	B.	B.
8·20	2690	2912	3151	3221	3195	3053
6·90	2602	2805	3045	3115	3089	2947
5·25	2460	2646	2886	2956	2929	2788
3·84	2301	2487	2727	2779	2752	2593
2·60	2142	2257	2515	2602	2558	2416
1·33	1929	2062	2320	2372	2328	2186
·59	1788	1938	2178	2213	2186	2044
0	1646	1798	1965	2018	2009	1850
− ·59	1434	1620	1805	1859	1832	1708
−1·33	1062	1230	1381	1451	1443	1389
−2·60	− 796	− 805	− 885	− 796	− 646	− 443
−3·84	−1752	−1920	−2106	−2071	−2009	−1584
−5·25	−2212	−2416	−2637	−2655	−2628	−2345
−6·90	−2496	−2735	−2974	−3027	−3000	−2805
−8·20	−2690	−2912	−3151	−3221	−3195	−3053

151° C.		151° C.		21° C.		21° C.	
H.	B.	H.	B.	H.	B.	H.	B.
8·20	2982	− ·59	1602	8·20	2951	− ·59	1582
6·90	2876	−1·33	1301	6·78	2840	−1·30	1304
5·25	2717	−2·60	168	5·13	2674	−2·54	379
3·84	2540	−3·84	−1319	3·78	2489	−3·78	−1008
2·60	2363	−5·25	−2186	2·54	2286	−5·13	−2026
1·33	2115	−6·90	−2700	1·30	2064	−6·78	−2636
·59	1956	−8·20	−2982	·59	1916	−8·20	−2951
0	1832			0	1804		

The observations obtained from the experiments with rising temperatures are indicated thus ×, and those obtained from the experiments with falling temperatures ⊙.

It will be seen that the curves develop maxima at the temperatures 570° and 530° C. respectively.

If these curves be compared with the corresponding double reversal curves fig. 3, it will be seen that the hysteresis loss falls off as the induction increases, reaches a minimum value at a temperature about 100° higher than the temperature of maximum induction, and attains a second maximum when the induction has about half its maximum value.

Variation of Hysteresis Loss with Temperature.
Limits of Field-strength +8·2 and −8·2.

Experiments with rising Temperatures.		Experiments with falling Temperatures.	
Temperature in degrees cent.	Hysteresis Loss in ergs per c.c.	Temperature in degrees cent.	Hysteresis Loss in ergs per c.c.
24	2132	21	2092
159	2019	151	2035
226	1939	234	1940
311	1733	284	1892
361	1550	330	1892
370	1526	354	1793
381	1447	370	1700
392	1272	388	1502
416	1240	394	1478
441	1161	428	1383
449	1177	454	1320
460	1240	471	1335
502	1224	501	1400
527	1178	544	1368
569	1399	583	588
582	1178		
587	1082		
602	354		
642	57		

The relation between the Coercive Force and the Temperature is shown on Pl. VI., and was obtained from the following readings .—

Data.

With rising Temperatures.		With falling Temperatures.	
Temperature.	Coercive Force.	Temperature.	Coercive Force.
24° C.	2·7	21° C.	2·9
159	2·5	151	2·7
226	2·3	234	2·4
311	2·0	284	2·3
361	1·8	330	2·3
370	1·7	354	2·1
381	1·6	370	2·1
392	1·5	388	2·1
416	1·8	394	2·2
441	1·7	428	2·3
449	1·7	454	2·2
460	1·8	471	2·4
502	2·0	501	2·5
527	2·2	544	2·9
569	3·3	583	2·4
582	3·4		
587	3·6		
602	2·2		

§ VI. *Experiments on the Changes in the B and T curves due to successive Heatings and Coolings.*

The magnetic properties of the specimen change to some extent after heating to a high temperature.

The difference between two successive B and T curves (H = a constant) is much smaller for strong than for weak fields.

In all the cases tried the characteristic form of the curve was maintained. The nature of this change can be seen from a consideration of the curves shown on fig. 3.

The curves A and B were obtained from double reversal throws taken simultaneously with the hysteresis loops for rising temperatures.

They were plotted from readings which are indicated on the diagram thus ×.

In the figures T stands for the temperature in degrees centigrade, B for the maximum induction reached at each reversal, and H for the field-strength in C.G.S. units.

H = 8·2 C.G.S. units.		H = 3·48 C.G.S. units.	
T.	B.	T.	B.
24	3137	24	1364
159	3137	146	1468
226	3223	157	1487
311	3337	165	1535
361	3376	204	1621
370	3376	228	1697
381	3261	307	1955
392	2939	312	2021
416	2644	370	2269
449	2584	382	2241
502	2381	392	2035
527	2195	415	1858
569	1708	500	1522
582	1389	570	442
587	1257	594	248
602	628	640	106
642	221		

The specimen was then heated to 800° C., and double reversal throws were taken for fields of 8·2 and 3·48 units during cooling.

The values obtained are indicated thus * in fig. 3.

It will be seen that the magnetic properties have changed considerably owing to the repeated heatings and coolings.

H=8·2.		H=3·48.	
T.	B.	T.	B.
696	168	696	106
638	274	638	142
582	1027	580	292
564	1567	544	637
541	1910	500	1123
500	2195	477	1291
474	2319	450	1397
452	2380	428	1451
428	2425	408	1520
408	2495	394	1647
394	2780	388	1813
386	3035	369	1900
369	3265	360	1990
360	3320	354	1990
354	3320	326	1902
330	3328	293	1795
291	3293	235	1505
235	3185	152	1274
152	3062	20	1045
20	3015		

The specimen was next slowly heated to 434° C. and then slowly cooled, double-revesal throws being taken at intervals; the readings (not given) were found to lie on the last curve obtained.

The specimen was then unwound and rewound with cotton-covered copper wire soaked in melted paraffin, and double-reversal throws were taken at ordinary temperatures. The values obtained confirmed the preceding observations.

The ring was now wound with asbestos-insulated copper wire, the number of turns in the primary and secondary being the same as in the previous experiments with asbestos insulation.

The specimen was then heated by stages to 720° C. and cooled, double reversals being taken at each stage when the temperature was steady. This experiment lasted 36 hours.

These values are indicated on the diagram thus :—

⊙ for observations during heating,

⌖ for observations during cooling.

Observations during heating, indicated on fig. 3 thus, ⊙.

H=8·2.		H=3·48.	
T.	B.	T.	B.
16·5	2988	16·5	1034
114	3015	117	1175
186	3117	184	1369
251	3200	254	1516
280	3302	280	1720
307	3358	309	1877
334	3367	332	1942
360	3311	362	1998
377	2951	378	1757
387	2664	389	1583
398	2534	398	1517
436	2405	441	1452
487	2220	481	1249
555	1683	559	416
660	268	657	139
669	250	670	148
684	166	683	111
700	65	703	37
711	37	711	18

Observations during cooling indicated thus ┼ on fig. 3.

H=8·2.		H=3·48.	
T.	B.	T.	B.
688	111	683	102
630	240	630	129
628	222	628	120
614	250	614	129
593	407	590	194
577	758	578	240
560	1406	560	361
528	1952	527	740
500	2201	502	1045
444	2442	444	1443
401	2534	402	1489
394	2553	394	1535
386	2682	387	1554
376	3062	376	1813
360	3311	360	1970
300	3340	298	1767
298	3367		

The curves obtained from these last two sets of readings approximate closely to one another throughout the greater part of their length. The authors have been led to the conclusion that the heating- and cooling-curves for this alloy are coincident only when the highest temperature reached in the experiments is considerably less than the temperature of minimum permeability. When the temperature approaches this value the magnetic properties of the specimen change, and a new curve connecting the induction and temperature is obtained.

Table of Values of H and B at Atmospheric Temperatures.

I. From Observations in 1897.		II. From Observations in March 1900.	
H.	B.	H.	B.
0·94	216	0·6	93
1·55	469	1·04	208
2·20	675	1·73	375
3·45	1674	2·88	853
4·40	2200	4·03	1435
5·39	2614	5·76	2187
6·59	2990	6·91	2540
7·82	3294	8·63	2980
8·99	3540	11·50	3480
9·40	3630	12·65	3620
11·19	3906	14·38	3835
13·19	4180	17·27	4125
14·87	4394	20·93	4415
18·36	4720	23·85	4620
27·20	5310	26·72	4785
32·70	5680	29·60	4975
33·00	5670	32·47	5145

In the accompanying table is given a series of values of the induction and field strength at ordinary temperatures, obtained (i.) in the summer of 1897, and (ii.) in March 1900.

The two curves connecting them are shown as I and II on fig. 4. It will be seen from these curves that the effect of repeated heating and cooling is to diminish the permeability of the specimen.

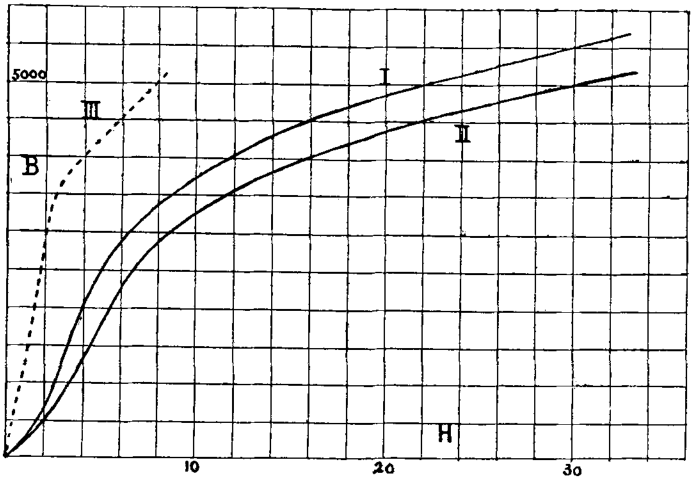
Let us seek for an explanation of this unexpected result.

It is known that impure specimens of iron containing large amounts of aluminium disintegrate in course of time. It is hence not unlikely that the same process is at work in specimens containing less aluminium, though in a less marked degree.

The microscopic examination of the specimens shows the presence of crystals.

The coefficients of expansion of these crystals are probably different from the coefficient of expansion of the surrounding matrix; and since solidification takes place at a high temperature, the material of the specimens would, at ordinary temperatures, be in a strained condition.

Fig. 4.



The effect of repeated heating and cooling would gradually produce disintegration.

Let us assume that the change in the magnetic condition due to this breaking down of the material of the specimen is, to a first approximation, equivalent to the introduction of an air-gap in the magnetic circuit.

If this were the case, the actual magnetic force in the specimen would be less than that due to the magnetizing-current alone.

Let us assume that, after a certain number of heatings, the only change going on is due to disintegration, and that the actual force in the specimen can be represented approximately by the expression $(H-KB)$ (as would be the case with a split ring), where $H=$ the magnetic force due to the spiral alone, and K is some constant depending upon the number and size of the gaps in the specimen (due to disintegration). If then H_1, H_2 be the values of H on the two curves I and II (fig 4) corresponding to a given value of B, we should, on the above assumption, have the relation

$$H_1-K_1B=H_2-K_2B,$$

where K_1, K_2 are the two values of K for the two curves considered, or

$$\frac{H_1-H_2}{B}=(K_1-K_2)=\text{constant}.$$

Hence, on the above assumption, the curve connecting (H_1-H_2) and B should be a straight line. This curve is shown as III on fig. 4.

It will be seen that this curve differs considerably from a straight line. It is interesting, however, to compare these curves with some obtained by Mr. C. G. Lamb (Phil. Mag. Sept. 1899). Mr. Lamb experimented on a piece of iron first in the form of a bar, and secondly in the form of a ring. The B and H curves for the ring and bar are shown in Mr. Lamb's paper on fig. V. as R and P respectively.

If now H_1, H_2 are the field-strengths corresponding to a given value of B for these two curves, then $\frac{H_1-H_2}{B}$ should theoretically be a constant, and the curve connecting (H_1-H_2) and B should be a straight line.

If, however, a curve connecting (H_1-H_2) and B be plotted from the two sets of observations in question, it will be found to differ from a straight line, and to be very similar in general form to curve III above. Hence it is concluded that the assumption made to explain the change in the permeability of the alloy due to repeated heating and cooling is probably much nearer the truth than the form of curve III would at first sight seem to indicate.

§ VII. *Experiments near the Temperature of Minimum Permeability.*

A third set of experiments were undertaken to trace the changes in the induction (with a constant field) with change of temperature in the neighbourhood of the temperature of minimum permeability.

As mentioned in Part I., an abrupt change in the permeability is observed at a temperature somewhat less than this.

This abrupt change was more marked during cooling than during heating. It attained its maximum value at a temperature of 652° C. with rising temperatures, and at a temperature of 645° C. with falling temperatures.

This small difference of 7° C. might be due to the temperature of the ring lagging behind the temperature of the thermometer. As, however, the heating and cooling were conducted very slowly, the authors believe it to be a true temperature hysteresis effect.

The balance method (described in Part I.) was used in these experiments. This method, which is inapplicable when the permeability is large (except in the case of laminated rings), enables *small* permeabilities to be determined with ease and accuracy.

The curves obtained are shown on fig. 5 and were plotted from the following readings.

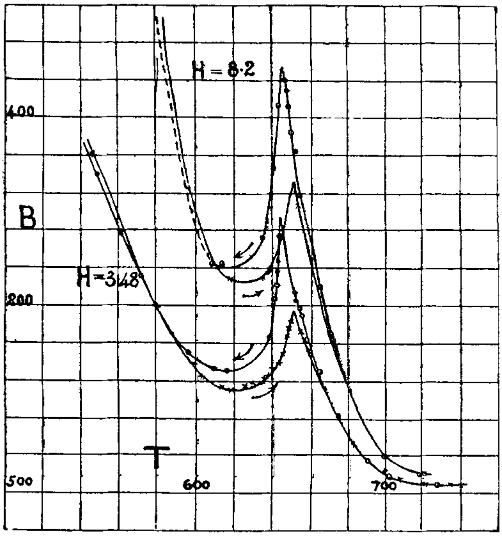
First Series : with rising Temperatures.

H=8·2.		H=3·48.	
T.	B.	T.	B.
584	496	547	360
601	294	580	197
606	262	594	152
619	227	600	136
636	227	604	122
644	258	614	112
650	319	619	108
653	324	626	112
654	303	630	115
656	275	635	116
663	222	637	120
683	97	638	123
697	48	640	130
		643	134
		644	136
		646	147
		648	165
		649	174
		650	179
		655	172
		657	162
		660	148
		665	131
		683	53
		700	21·4
		703	16·9
		708	13·0
		722	7·3
		735	7·1
		741	6·4

Second Series: with falling Temperatures.

H=8·2.		H=3·48.	
T.	B.	T.	B.
721	19·1	741	6·4
719	19·7	728	7·4
700	38·0	702	16·6
671	168	691	32·8
666	218	675	80·5
655	314	667	127·5
652	362	656	187
650	383	655	195
649	411	653	203
648	427	652·5	211
647	439	645	272
644	412	644	250
641	344	643·5	236
635	270	643	220
614	242	642	205
609	243	639	164
		617	129
		610	131
		597	148
		573	230
		562	274
		550	338

Fig. 5.



§ VIII. *The Relation between the Temperature of Minimum Permeability and the Percentage of Aluminium in the Specimens.*

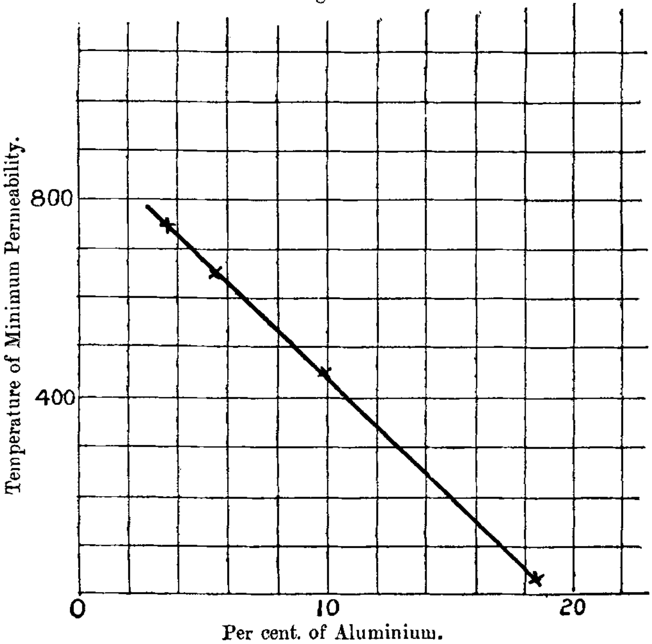
It is not possible to say, with any degree of precision, at what temperature the permeability of a specimen attains its minimum value, as the change of permeability with temperature is very gradual in the neighbourhood of the temperature of minimum permeability. It also appears to depend to some extent on the strength of the field considered, being higher for strong than for weak fields.

For the specimens so far investigated the following approximate values of the temperature of minimum permeability have been obtained.

Per cent. of Aluminium.	Temperature of Minimum Permeability.
3·64	750° C.
5·44	650
9·89	450
18·47	25

A curve connecting these values is shown as fig. 6. This curve will be seen to be a straight line.

Fig. 6.



§ IX. *The Microstructure of the Alloys.*

It has been suggested in Part I. that the general behaviour of the alloys might be explained on the assumption that they consisted of crystals surrounded by a solidified mother-liquid.

With a view to ascertaining if this was the case the specimens, after grinding and polishing, were etched with dilute nitric acid and examined microscopically. The eyepiece of the microscope was then removed, and the adjustment was altered until the image fell on the screen of a camera.

When as clear an image as possible was obtained on the screen, a slow plate was exposed for about 15 minutes.

In this way photographs (Pl. VI.) were obtained showing the forms of the crystals in the specimens containing 5·44, 9·89, and 18·47 per cent. of aluminium respectively.

Photograph A. (Specimen containing 5·44 per cent. of Al.) Crystals can be seen in the form of Maltese crosses.

Photograph B. (Specimen containing 9·89 per cent. of Al.) In places crystals having the appearance of a number of rods placed side by side can be seen. Generally the rows are arranged in pairs, the distribution being not unlike that of the bones of a herring.

Photograph C. (Specimen containing 18·47 per cent. of Al.) The crystals are similar to those shown in photograph B; but are larger in size.

The magnification of A and C is about 25 diameters. The magnification of B is about 50 diameters.

An investigation on the magnetic properties of pure alloys of iron and aluminium is now in progress, and we hope very shortly to publish an account of some of the earlier experiments on these purer specimens*.

University College, Nottingham,
June 7th, 1900.

LXI. *On Cyanine Prisms and a New Method of exhibiting Anomalous Dispersion.* *By* R. W. Wood†.

I HAVE already described a method of making prisms of solid cyanine by pressing the fused dye between plates of glass, which are far superior to liquid prisms or the solid prisms made by Wernicke for the purpose of exhibiting anomalous dispersion.

Until quite recently I considered that twenty or thirty minutes was about as large an angle as could be used to advantage. With such large angles very little green light

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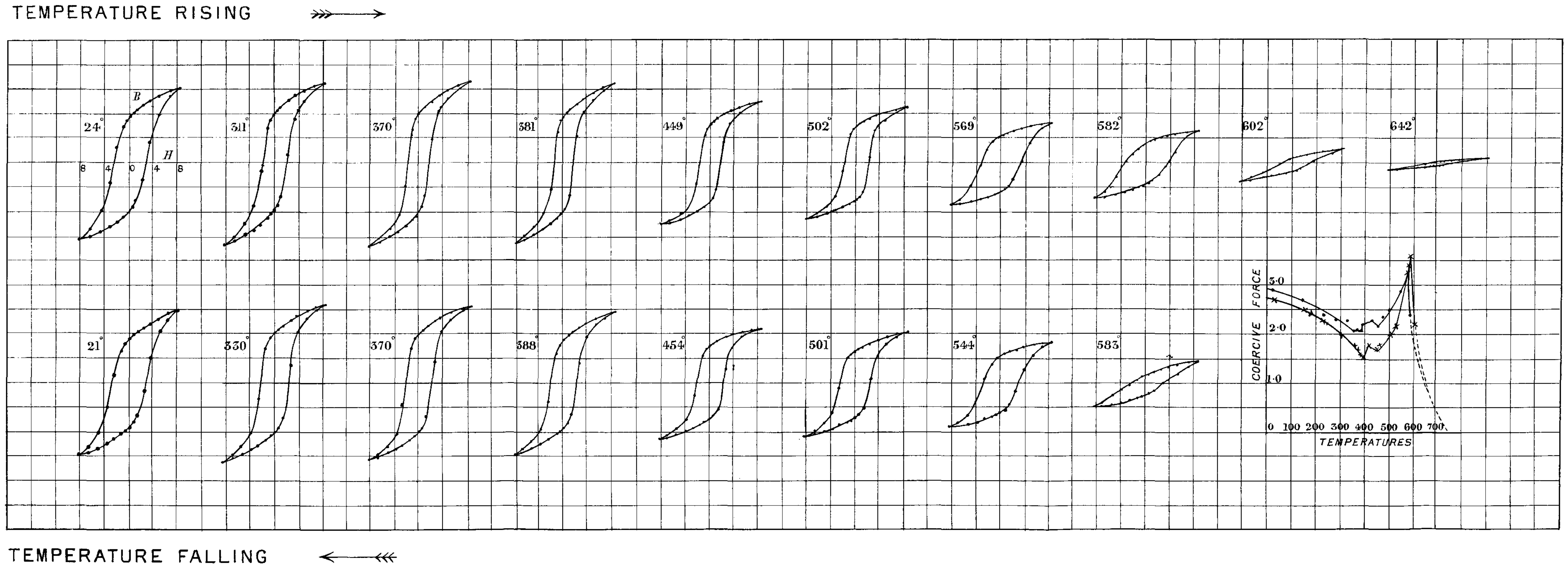
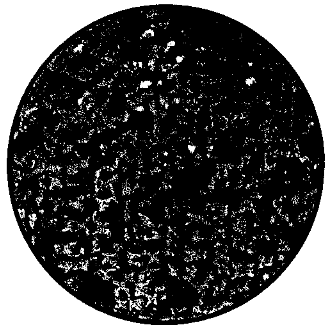
* *Vide* Phil, Mag. March 1901.

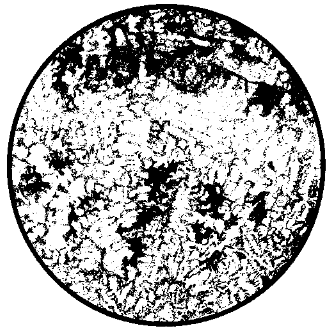
† Communicated by the Physical Society: read Feb. 22, 1901.

Phil. Mag. S. 6. Vol. 1. Pl. VI.

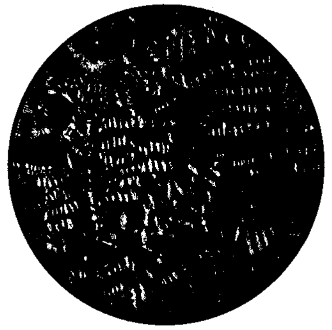




A.



B



C

Mintern Bros. lith.