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The Wiedemann Effect in Ferromagnetic Substances.

By

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With Plates I–III.

The Wiedemann effect in iron and nickel is so well known that it is superfluous to enter into the details of the phenomenon. The experiments by G. Wiedemann,(1) C. G. Knott,(2) Professor Nagaoka and one of our members(3) show that so long as the longitudinal field is not strong, the direction of twist in iron coincides with that of a circular field, if this direction is right-handedly related to that of the longitudinal field; they also show that in nickel the direction of twist is opposite to that of iron. In strong field, however, the direction of twist in iron is reversed, so that iron and nickel are twisted in the same direction. The direction of twist is reversed, when one of the circular and longitudinal fields changes its direction. Wiedemann effect in nickel steels of different percentages was recently studied by Professor Nagaoka and one of our members, and it was found that the direction of twist was the same as that of iron. The effect of tension on the Wiedemann effect in iron and nickel was

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1) G. Wiedemann, Pogg. Ann. **103**, 571, 1858; **106**, 161, 1859; Electricität III, 797.

2) Knott, Trans. Roy. Soc. Edinb. **32** (1), 193, 1882/83; **35** (2), 377, 1889; **36** (2), 485, 1891.

3) Nagaoka and Honda, Jour. of Coll. of Sci., XIII, 263, 1900.

examined by C. G. Knott who found that the tension diminished the angle of twist in these metals.

The present paper consists of two parts: firstly we deal with the influence of tension on the Wiedemann effect in nickel steels, and secondly with the same effect in ferromagnetic bars and the effect of torque on it. We lately published a paper relating to the effect of tension on the magnetic change of length ; in this we found that the magnetic elongation of nickel steels is largely affected by tension, and that when the tension exceeds a certain value, the contraction is accompanied by magnetization. From Maxwell and Crystal's explanation as well as from that of Kirchhoff for the Wiedemann effect, it seems probable that the direction of twist in nickel steels is reversed, when the suspended weight exceeds the said limit. We therefore studied this point particularly and found that the above inference is not correct.

So far as we are aware, Wiedemann effect in cobalt has not yet been studied, perhaps because it is difficult to obtain a specimen in the form of a wire on account of its brittleness. It was therefore desirable to have an experiment for the metal. Our apparatus used in studying the change of rigidity by magnetization was conveniently used for examining the Wiedemann effect of ferromagnetic bars. We had two cobalt bars, one in the cast state and the other in the annealed. The observations showed that the torsion in cobalt was opposite to that of iron, as was to be expected from the change in length by magnetization.

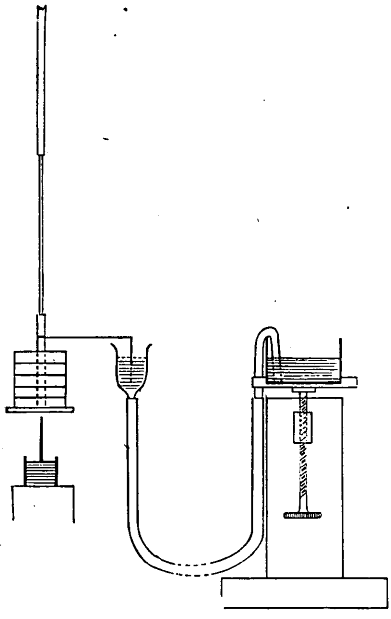
We tested 8 different samples shown in the following table :—

Metal.	Length.	Diameter.
45% nickel steel	20.80 cm.	0.0956 cm.
" " "	20.90	0.0516
35% nickel steel	20.92	0.0939
" " "	20.96	0.0509
Soft iron bar	21.03	1.004
Nickel bar	21.00	1.117
Cast cobalt bar	21.00	1.038
Ann. cobalt bar	21.00	1.082

Our arrangement for studying the Wiedemann effect in nickel steel wires was the same as that used by Professor Nagaoka and one of our members in the experiment described in the paper above referred to.

To the extremities of a nickel steel wire 21cm. long were brazed stout brass wires, and a light mirror was attached to the lower brass wire. The upper wire was clamped to a small tripod, which rested on the top of a magnetizing coil provided with hole, slot, and plane arrangement. One end of the accumulator was connected with the tripod, while the other was led to the mercury pool placed under the suspended wire. The wire hung vertically in the axial line of the coil, which was 30cm. long and gave a field of 37.97 *C.G.S.* units at the center by passing a current of one ampere. The vertical component of the terrestrial magnetic field was compensated by placing another coil in the interior of the magnetizing coil. The twist was measured by scale and telescope, by which a torsion of 0.2″ per cm. was easily read.

The preliminary experiment showed that the resistance to the twist offered by the mercury in the pool was not negligibly small, when the thick brass wire was dipped into the mercury. The resistance was especially noticeable, when the brass wire carried a narrow rectangular piece for the purpose of damping. Hence in order to efface the resistance, a non-magnetic nickel steel wire 0.5mm. thick and 5cm. long was soldered to the lower end of the brass wire and dipped into the mercury pool. By this, the damping of the torsional oscillation was rendered very small, especially in the case when a weight was attached. To stop the oscillation, a brass wire was fixed horizontally to the vertical wire and bent downward as shown in the annexed figure. Just below it, a small mercury cup was placed ; this cup was connected with a large one by a caoutchouc tube. This large cup was placed near the observers and could be raised or lowered by means of a screw adjustment. This motion caused the mercury in the small cup to be raised or lowered, so that the side wire dipped into the mercury, or hung free. When we wished to stop the oscillation of the wire, the side wire was dipped into the mercury in the small cup ; while the reading was always taken with the wire hanging free of the mercury.



The experiment was conducted in the following manner:—

1. The circularly magnetizing current was kept constant, and the amount of twist measured by varying the longitudinally magnetizing current.

2. The wire was then stretched by different loads and the above processes were repeated.
3. The longitudinally magnetizing current was kept constant, and the amount of twist measured by varying the circularly magnetizing current.

Before each experiment care was taken to demagnetize the wire completely either longitudinally or circularly by passing an alternate current of gradually diminishing intensity. This was found absolutely necessary to secure correct results.

Twist by varying the longitudinal field. If the direction of the longitudinal field is right-handedly related to that of the circular field, nickel steel is twisted in the direction of the latter. As shown in Figs. 1 and 2, under a given circular field, the amount of twist at first increases till it reaches a maximum, after which it gradually diminishes. But the reversal of the twist is never observed, though the field exceeds 1200 *C.G.S.* units. The position of the maximum twist is slightly displaced in high fields as the longitudinal current increases. The amount of twist is greater in 45% nickel steel than in 35% nickel steel. Some observed readings are given in the following tables :—

45% nickel steel.

$C=0.95$ amp.		$C=1.93$ amp.		$C=3.00$ amp.	
H	θ	H	θ	H	θ
0.2	2.2″	0.2	3.6″	0.2	3.7″
3.6	21.7	2.0	20.6	4.5	41.6
9.3	27.0	6.7	43.2	6.9	54.8
17.3	25.3	11.5	47.7	19.7	66.4
32.0	19.9	31.7	39.8	33.0	57.8
51.2	15.3	51.3	31.1	51.7	45.5
89.2	9.9	89.6	20.3	91.3	29.9
158	5.5	158	12.2	163	17.7
277	2.5	283	7.3	296	9.9
462	1.4	462	4.1	496	5.9
655	0.3	655	2.8	727	3.7

35% nickel steel.

$C=0.76$ amp.		$C=1.59$ amp.		$C=3.09$ amp.	
H	θ	H	θ	H	θ
0.3	1.8″	0.3	2.2″	0.3	2.9″
1.9	5.8	0.8	4.9	1.8	14.5
5.0	11.8	3.0	15.3	5.0	31.4
10.0	14.9	9.6	27.6	10.7	40.8
25.5	12.3	20.9	25.1	17.6	41.2
38.6	9.8	30.3	21.2	28.7	32.0
51.4	8.0	51.3	14.7	51.3	22.0
89.6	5.1	102.8	8.2	102.8	12.7
183	2.6	204	4.3	205	7.3
352	1.6	448	2.1	448	3.9
619	0.9	668	1.7	668	2.9

Here C denotes the current per square millimeter, H the external field and θ the angle of twist per centimeter. In the experiment above cited, Professor Nagaoka and one of us observed in some cases the reversal of the direction of twist in 45% nickel steel; but in the present experiment, we did not notice this reversal of twist.

The effect of tension. The effect of tension on twist in nickel steels is not so marked as that of tension on the magnetic change of length in the same metal. As seen from Figs. 3 and 4, the tension always diminishes the amount of twist; the diminution is large in weak fields and becomes gradually less as the field is increased, till it becomes insensibly small. The diminution is approximately proportional to the applied tension.

To test the effect of heavy loading, thin wires about $\frac{1}{2}$mm. thick were examined. Even by a tension in which contraction occurs by magnetization, the direction of torsion in nickel steels is not reversed, though the amount of the maximum twist is reduced to about ^{1} or $\frac{1}{5}$ its value corresponding to no tension, as seen from Figs. 5 and 6.

Whichever theory we adopt, whether Maxwell's or Kirchhoff's, the direction of twist is principally determined by the sign of the quantity $3\lambda-\sigma$, where λ and σ are respectively the length- and the volume-change of the ferromagnetics. When there is no tension acting on the wire, the sign of $3\lambda-\sigma$ must be positive, because the direction of twist in the alloy is the same as that of iron. By applying a heavy load, the contraction is accompanied by magnetization so that λ is negative. Hence in order that $3\lambda-\sigma$ should be positive, σ must necessarily be negative under heavy loading; that is, the change of volume by magnetization must change its sign from positive to negative, as the load is increased.

Twist by varying the circular field. In Figs. 7 and 8, we notice that under a constant longitudinal field, the angle of twist at first increases at a constant rate, but later at a gradually diminishing rate. As the longitudinal field is increased, the curves approximate to right lines, a result which is to be expected from Kirchhoff's theory of magnetostriction. For according to the theory, if the circular field is small compared with the longitudinal field, the amount of twist for a given longitudinal field is proportional to the longitudinal current. The amount of twist is greater in 45% nickel steel than in 35% nickel steel.

From Figs 7 and 8, we can obtain the twist under a given longitudinal current by gradually increasing the longitudinal field; the result so obtained, if it is compared with Figs. 1 and 2, shows that the twist produced by the interaction of the circular and longitudinal fields is independent of the order of applying them.

Some observed angles of twist are exhibited in the following tables:—

45% nickel steel.

H=4.8		H=12.8		H=66.5		H=323.0	
C	θ	C	θ	C	θ	C	θ
0.25	4.9″	0.14	3.7″	0 27	3.6″	0.21	0.5″
0.45	10.0	0.40	9.4	0.62	8.3	0.59	1.8
0.99	22.1	0.99	25.0	0 82	10.8	1.13	3.5
1.69	33.3	1.75	41.6	1.41	19.0	1.55	4.4
3.00	43.0	2.53	55.4	2.06	26.6	2.40	7.5
—	—	3.64	70.2	3.39	41.4	3.47	11.0

35% nickel steel.

$H=2.1$		$H=13.8$		$H=32.7$		$H=89.6$	
C	θ	C	θ	C	θ	C	θ
0.29	2.0″	0.15	2.4″	0.25	3.4″	0.24	1.5″
0.56	3.7	0.56	9.6	0.56	7.5	0.57	3.5
1.05	7.6	1.05	18.0	1.05	13.5	1.05	6.2
2.23	13.7	2·24	35.0	2.06	24.1	2.04	12.2
3.08	15.7	3.07	40.8	3.10	31.8	3.07	15.7

The apparatus for studying the Wiedemann effect in ferromagnetic bars was that used in the experiment on the change of rigidity by magnetization; the longitudinal current was led to the bar by means of mercury contact without causing sensible resistance. The ferromagnetic bar was soldered on both ends to brass bars of a thicker diameter, as in the former experiment just referred to. It was fixed, by means of the screw nut at one end of the bar, in the axial line of the magnetizing coil, which was placed magnetic east and west. The pivot at the other end of the bar carrying a double wheel was lightly placed in contact with the agate cup fixed to the wooden frame. The twist was measured by means of a rotating cylinder with a reflecting mirror, a vertical scale and a telescope. Since the Wiedemann effect is an odd function of longitudinal or circular fields, it is easily distinguishable from other effects such as the change of elasticity or that of rigidity, which is an even function of the field. Preliminary experiments showed that the circular field has no effect upon the modulus of elasticity or of rigidity, perhaps because the field is not strong enough to cause such changes. They also showed that the friction at the pivot is not sensible; for the amount of twist when the pivot is left free or when it is supported, gave almost coincident values. The direction of currents was also so chosen that the rotation of the mirror causes contraction of the weak spring stretching the thin copper wire. With the present apparatus, the twist amounting only to $1.83'' \times 10^{-3}$ per cm. of our specimen was easily read.

The measurement was conducted in the same order as in the case of nickel steels. Here we noticed that a slight residual magnetism considerably affected our results; hence before each deflection was taken, demagnetization was carefully effected.

Twist by varying the longitudinal field. Fig. 9 represents the curves of twist per cm. in an iron bar plotted against the external longitudinal field. Here C is the longitudinal current per square centimeter. The general course of the curves is similar to that observed in the wire of the same metal. Under a constant circular field, the angle of twist increases at first slowly and then rapidly, till it reaches a maximum in a field of about 100 *C.G.S.* units ; it then diminishes and ultimately changes its direction. The field in which the twist reaches a maximum, and also the field of reversal are markedly larger in the bar than in the wire. Moreover, the diminution of twist in the bar, after reaching a maximum, is comparatively slow.

The results for nickel are drawn in Fig. 10; the general features of the curves are similar to those in the wire of the same metal. The direction of twist is opposite to that in iron ; but the course of the curves is similar to that in iron, the only difference being that even in strong fields, the direction of twist is not reversed. The field in which the twist reaches a maximum is also considerably larger in the bar than in the wire, and the diminution of twist, after reaching a maximum, is comparatively slow.

The direction of twist in cobalt is the same as in nickel. In cast cobalt, the amount of twist is rather large, as shown in Fig. 11. The twist increases at first slowly and then rapidly, till it reaches a maximum ; it then gradually decreases and ultimately changes its direction as the field is increased. Thus, the course of the curves is just the reverse of that in iron.

The behaviour of annealed cobalt as regards the Wiedemann effect is remarkably different from that of cast cobalt, as shown in Fig. 12. In the first place, the amount of twist is much smaller in the annealed than in the cast cobalt. Secondly, the field in which the twist reaches its maximum is rather large in annealed cobalt. Thirdly, the decrease of the twist after its maximum value is very slow and its direction does not change, though the field is pushed to 1200 *C.G.S.* units. These results for annealed as well as for cast cobalt are just what is to be expected from the magnetostriction of these specimens. It is also to be observed that these cobalt bars were made of different samples.

The following tables contain some observed angles of twist for iron, nickel, and cobalt bars :—

Iron bar.

$C=0.64$ amp.		$C=3.12$ amp.		$C=5.26$ amp.		$C=8.86$ amp.	
H	θ	H	θ	H	θ	H	θ
12.8	0.004″	12.3	0.029″	11.5	0.016″	12.3	0.069″
25.3	0.013	25.0	0.051	22.4	0.064	22.9	0.154
36.9	0.026	36.5	0.135	36.5	0.213	36.5	0.415
54.8	0.055	54.6	0.269	54.6	0.463	54.6	0.755
83.7	0.084	83.9	0.445	83.7	0.663	83.6	0.942
127.2	0.080	127.2	0.380	127.2	0.597	127.2	0.781
188	0.068	188	0.292	188	0.384	188	0.565
277	0.042	275	0.171	276	0.245	275	0.318
416	0.016	416	0.092	416	0.110	416	0.159
513	0.005	513	0.065	512	0.096	512	0.101
734	−0.005	729	0.016	726	0.053	726	0.040

Nickel bar.

$C=1.30$ amp.		$C=2.60$ amp.		$C=4.37$ amp.		$C=6.55$ amp.	
H	θ	H	θ	H	θ	H	θ
10.0	−0.141″	7.1	−0.183″	7.7	−0.297″	6.9	−0.336
14.4	−0.201	15.5	−0.424	15.7	−0.629	14.4	−0.767
26.4	−0.294	25.1	−0.632	25.0	−0.893	23.8	−1.158
40.6	−0.327	35.9	−0.705	35.9	−1.020	35.9	−1.372
53.3	−0.283	54.1	−0.684	53.8	−1.005	54.0	−1.358
81.1	−0.204	82.6	−0.523	81.5	−0.810	81.9	−1.125
123.8	−0.117	124.6	−0.367	124.8	−0.585	125.0	−0.840
186	−0.058	187	−0.236	187	−0.386	187	−0.595
270	−0.029	271	−0.141	272	−0.232	272	−0.391
408	−0.025	413	−0.086	408	−0.155	394	−0.292
512	−0.020	520	−0.065	512	−0.143	513	−0.223
670	−0.011	705	−0.040	708	−0.073	705	−0.143
797	−0.004	801	−0.024	802	−0.068	801	−0.104

Cast cobalt bar.

$C=2.34$ amp.		$C=4.75$ amp.		$C=9.19$ amp.		$C=17.22$ amp.	
H	θ	H	θ	H	θ	H	θ
12.5	−0.113″	11.9	−0.192″	12.5	−0.309″	11.2	−0.369″
27.6	−0.256	25.2	−0.406	26.0	−0.640	25.8	−0.929
40.8	−0.336	40.5	−0.574	40.7	−0.910	40.4	−1.340
62.3	−0.360	62.3	−0.638	62.5	−1.056	62.3	−1.648
81.1	−0.324	81.1	−0.594	81.1	−0.993	81.1	−1.600
123.8	−0.238	123.8	−0.444	123.8	−0.761	123.8	−1.248
184	−0.170	185	−0.285	185	−0.501	184	−0.834
281	−0.101	281	−0.181	279	−0.294	278	−0.490
385	−0.058	389	−0.113	386	−0.179	376	−0.265
510	−0.016	510	−0.055	510	−0.091	510	−0.150
686	+0.074	679	−0.004	683	−0.031	683	−0.049

Annealed cobalt bar.

$C=6.17$ amp.		$C=13.78$ amp.		$C=25.70$ amp	
H	θ	H	θ	H	θ
35.9	−0.011	35.8	−0.013	36.3	−0.022
81.1	−0.022	81.1	−0.031	81.1	−0.040
186	−0.040	180	−0.055	179	−0.073
269	−0.036	269	−0.053	269	−0.078
400	−0.033	397	−0.054	398	−0.073
492	−0.028	482	−0.045	493	−0.069
691	−0.023	675	−0.038	691	−0.067

Twist by varying the circular field. Fig. 13 represents the result for soft iron ; as the circular field is increased, the twist is increased first slowly and then rapidly. As the longitudinal field is increased, the amount of twist reaches a maximum and then gradually diminishes ; and if the field is strong enough, the twist occurs at first in the opposite direction and then in the ordinary. Comparing the above results with those obtained by varying the longitudinal field, we notice one marked difference that for the same circular and longitudinal fields, the torsion is largely dependent on the order in which they are applied. The twist obtained by first applying the circular field and then the longitudinal is several times greater than the twist obtained, when the order of applying them is reversed.

In nickel, the twist is opposite to that of iron ; under a given longitudinal field, it increases nearly in a constant rate as the longitudinal current is increased, as seen from Fig. 14. For a given longitudinal current, the twist reaches a maximum and then gradually diminishes as the longitudinal field is increased. Here again, we also observe a dependence of the twist on the order of applying longitudinal and circular fields. The twist obtained by the application of the circular field followed by that of the longitudinal one is far greater than the twist obtained when the order of application is reversed.

The general feature of the twist for cobalt is similar to that in nickel. In cast cobalt (Fig. 15), the twist is increased first slowly and then rapidly, as the circular field is increased. With the increase of the longitudinal field, the twist reaches a maximum and then gradually diminishes. If the longitudinal field be strong enough, the twist occurs at first in the opposite direction and then in the ordinary. In annealed cobalt (Fig. 16), the twist is very small and the rate of increase is nearly constant. Here also the twist obtained by first applying the circular field and then the longitudinal is several times greater than the twist when the order of application is reversed.

Some observed angles of twist in iron, nickel, and cobalt bars are given in the following tables. Here the current C is given in amperes per square centimeter.

Iron bar.

$H=8.2$		$H=31.7$		$H=64.1$		$H=163.4$	
C	θ	C	θ	C	θ	C	θ
6.4	0.000″	6.4	0.005″	6.4	0.003″	4.1	−0.002″
9.2	0.005	9.1	0.018	9.2	0.035	6.4	−0.003
13.3	0.015	13.3	0.051	13.4	0.093	9.2	−0.000
17.9	0.038	17.6	0.124	17.9	0.164	13.4	+0.037
24.8	0.109	24.8	0.360	24.7	0.472	17.7	+0.082
28.2	0.145	28.2	0.490	28.3	0.640	28.2	+0.290
37.6	0.203	33.3	0.643	33.3	0.935	33.1	+0.422

Nickel bar.

$H=9.9$		$H=31.7$		$H=72.6$		$H=239.8$	
C	θ	C	θ	C	θ	C	θ
1.0	−0.018″	1.1	−0.042″	1.1	−0.069″	1.1	−0.046″
2.3	−0.040	2.3	−0.109	2.3	−0.155	2.3	−0.112
5.1	−0.106	5.2	−0.285	5.2	−0.371	5.2	−0.256
7.5	−0.163	7.4	−0.395	7.5	−0.552	7.4	−0.373
10.9	−0.259	10.8	−0.621	10.9	−0.837	10.8	−0.555
14.4	−0.413	14.4	−0.891	14.5	−1.157	14.4	−0.749
20.1	−0.652	20.0	−1.372	20.2	−1.732	20.0	−1.078

Cast cobalt bar.

$H=7.4$		$H=65.7$		$H=220.6$		$H=603.0$	
C	θ	C	θ	C	θ	C	θ
1.8	−0.003″	1.9	−0.015″	1.9	−0.002″	0.7	+0.004″
3.7	−0.005	3.7	−0.073	3.7	−0.013	2.5	+0.018
5.9	−0.018	5.9	−0.137	5.9	−0 042	6.4	+0.024
8.5	−0.040	8.5	−0.305	8.5	−0.104	9.3	+0.025
12.4	−0.123	12.4	−0.567	12.5	−0 190	12.5	+0.027
16.5	−0.203	16.5	−0.906	16.6	−0.294	17.6	+0.037
23.0	−0.362	23.1	−1.433	23.0	−0.484	29.8	+0.000
31.8	−0.527	31.6	−2.078	31.5	−0.709	33.3	−0.027

Annealed cobalt bar.

$H=53.8$		$H=157.9$		$H=403.7$	
C	θ	C	θ	C	θ
5.5	−0.001	5.6	−0.002	5.5	−0.004
7.8	−0.002	8.2	−0.005	8.5	−0.009
11.3	−0.004	11.3	−0.009	13.5	−0.015
20.8	−0.009	17.6	−0.015	20.8	−0.026
28.1	−0.014	28.2	−0.027	28.2	−0.034
39.0	−0.019	45.3	−0.053	45.3	−0.061

The effect of torque. To study the effect of torque, it is convenient to keep the longitudinal field constant and to vary the circular field; for though the application of the longitudinal field is always accompanied by the twist due to the change of rigidity, the passage of a longitudinal current does not cause any appreciable twist; hence by varying the circular field, it is not necessary to apply the correction due to the change of rigidity. The torque was given by means of the suspended weights as in the experiment on the change of rigidity by magnetization. Keeping the longitudinal field constant, we found that in all cases the effect of torque diminishes the twist by an amount which is nearly proportional to the torque. Figs. 17, 18, 19, 20 show the general feature of the decrease of twist due to torque. In soft iron and annealed cobalt, the effect is very small, but in nickel and cast cobalt, it is considerable.

In a paper on mutual relations between torsion and magnetism, Professor Nagaoka and one of our members have obtained from Kirchhoff's theory the result that for given longitudinal current and field, the amount of twist is inversely proportional to the square of the radius of the ferromagnetic wire. It is interesting to notice that the comparison of the above results in iron and nickel bars 1*cm* thick, obtained by varying the longitudinal field, with the corresponding results in wires of these metals about 1*mm* thick, shows the correctness of the law of the inverse square of the radius.

In conclusion, we wish to express our best thanks to Professor H. Nagaoka for useful suggestions in the course of the present experiment.

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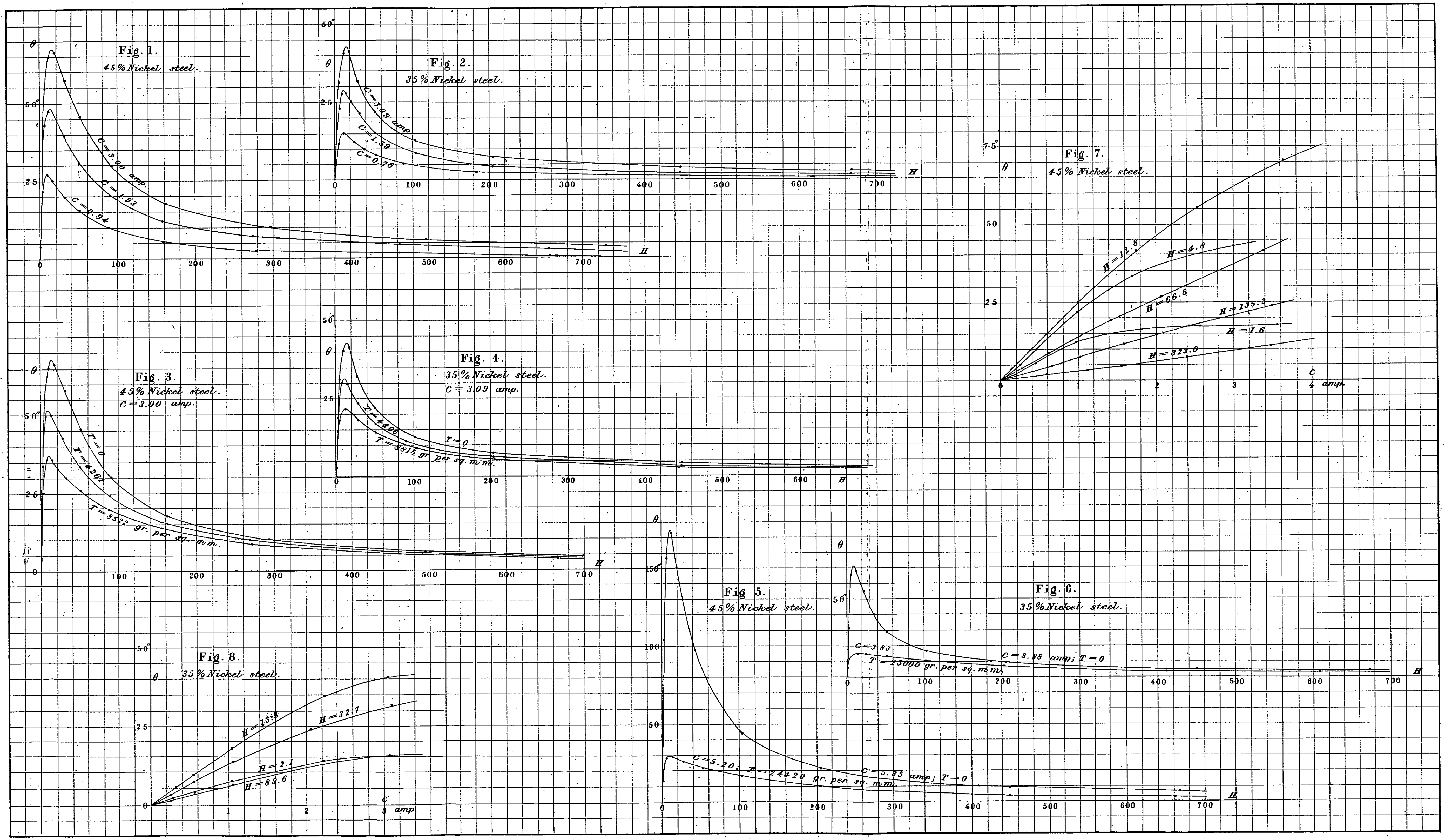

Fig. 1.
45% Nickel steel.

Fig. 2.
35% Nickel steel.

Fig. 3.
45% Nickel steel.
C=3.00 amp.

Fig. 4.
35% Nickel steel.
C=3.09 amp.

Fig 5.
45% Nickel steel.

Fig. 6.
35% Nickel steel.

Fig. 7.
45% Nickel steel.

Fig. 8.
35% Nickel steel.

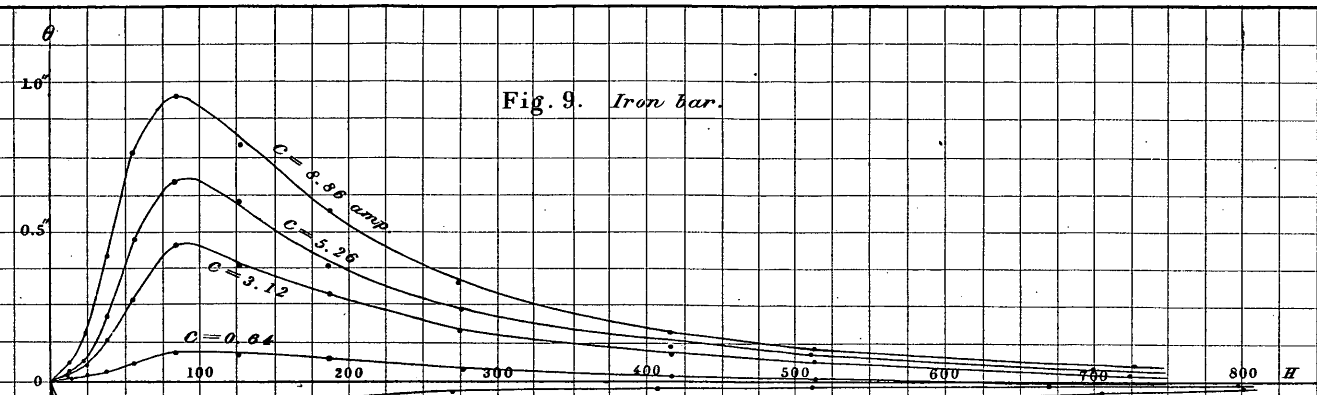

Fig. 9. *Iron bar.*

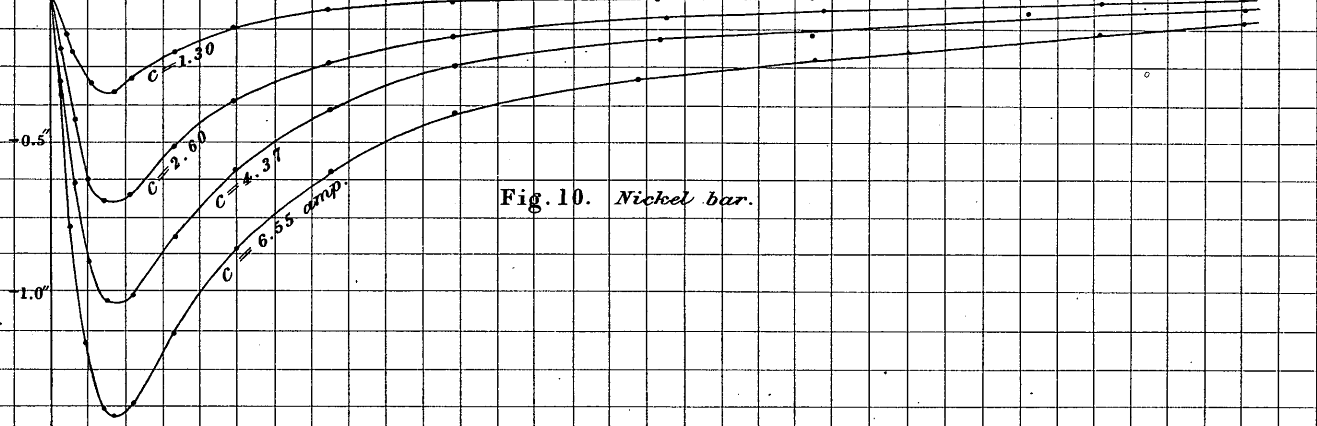

Fig. 10. *Nickel bar.*

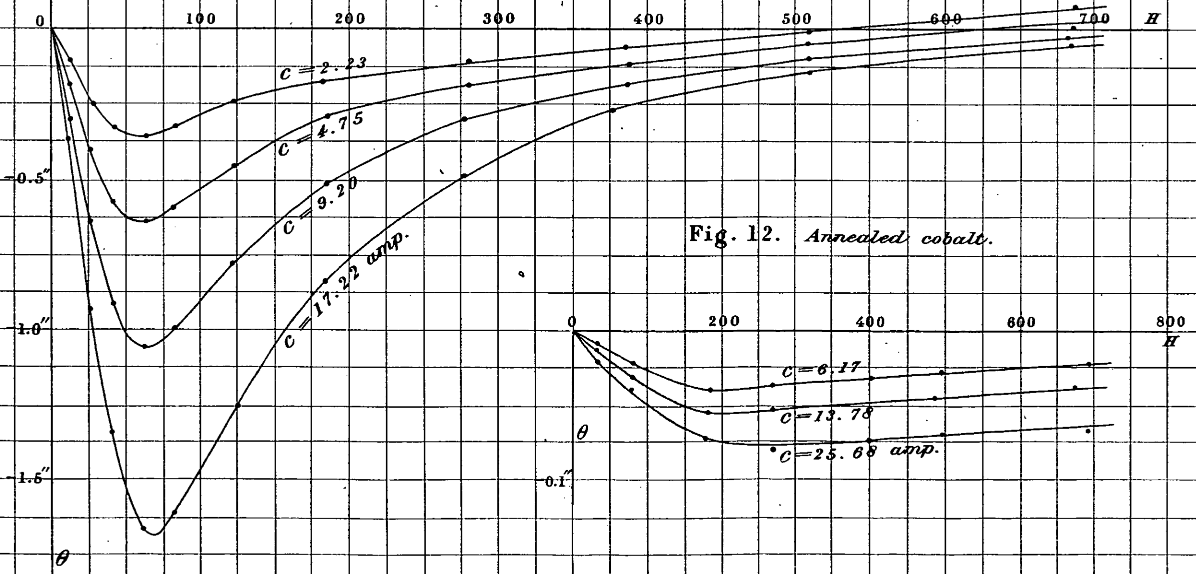

Fig. 11. *Cast cobalt.*

Fig. 12. *Annealed cobalt.*

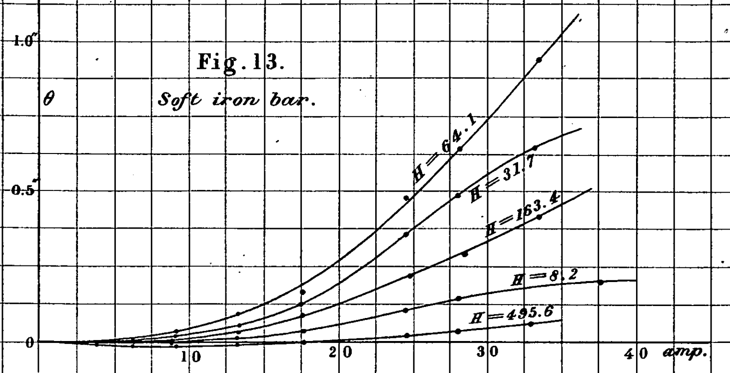

Fig. 13. *Soft iron bar.*

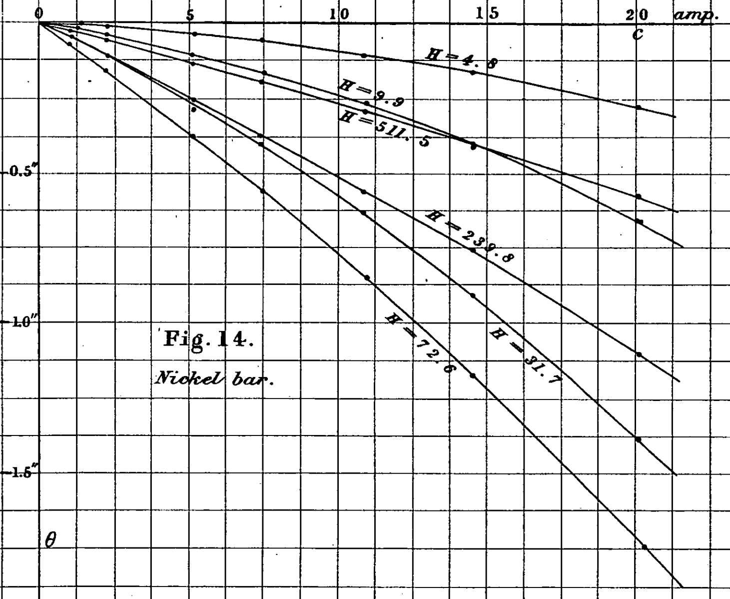

Fig. 14. *Nickel bar.*

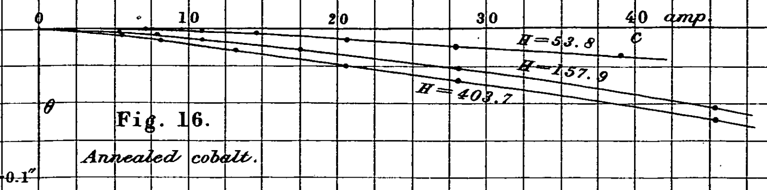

Fig. 16. *Annealed cobalt.*

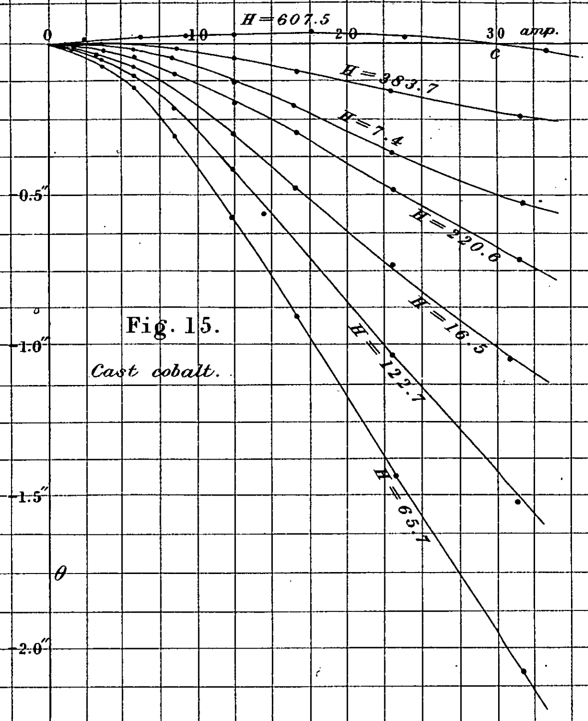

Fig. 15.

Cast cobalt.

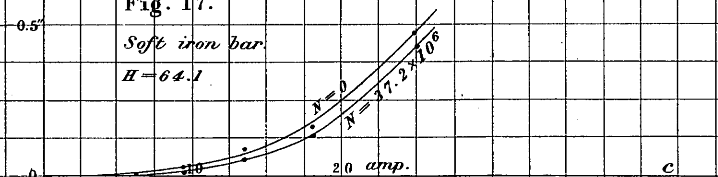

Fig. 17.

Soft iron bar.

H=64.1

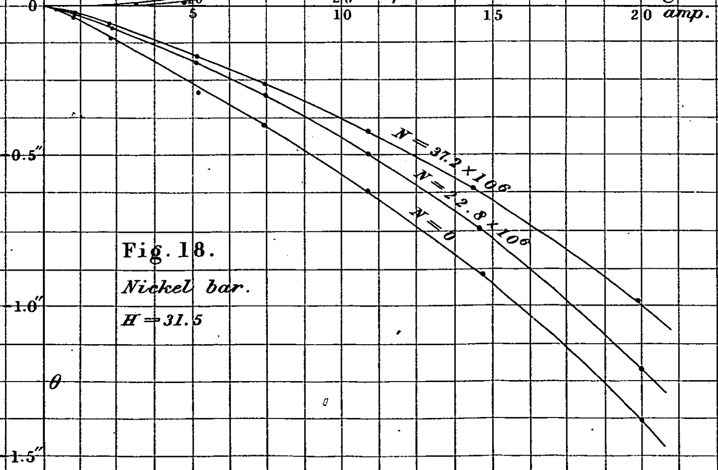

Fig. 18.

Nickel bar.

H=31.5

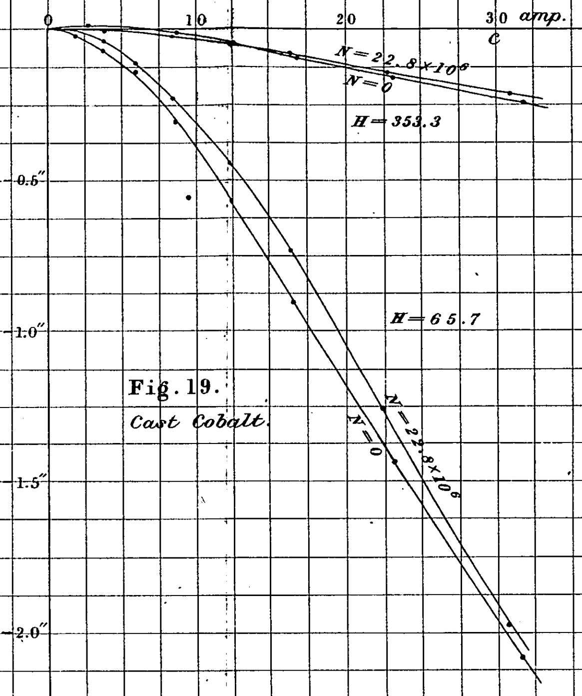

Fig. 19.

Cast Cobalt.

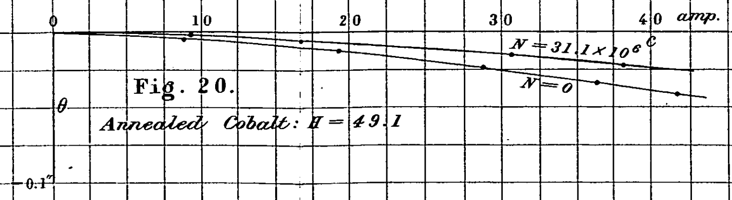

Fig. 20.

Annealed Cobalt: H=49.1