On the Magnetization and Retentiveness of Nickel Wire under combined Torsional and Longitudinal Stresses.

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With Plates XX – XXIV.

In the experiment described in the preceding paper, the magnetizing field around the nickel wire was kept constant, while the wire itself was subjected to varying twists. The quite unexpected results thus obtained suggested to me the advisability of examining carefully the magnetization of nickel wire at constant twists under the influence of gradually increasing and decreasing magnetizing fields. The distinct lines of research presented themselves; and the experiments naturally fall to be discussed under two heads.

(1.) There is the determination of the induced magnetism due to various magnetizing forces in a twisted nickel wire subjected at the same time to longitudinal stress.

(2.) There is the investigation of the relation between the induced and residual magnetisms under the conditions just specified.

I. Relation between Magnetization and Magnetizing Force.

The experiments to be described are concerned with the peculiarities of magnetization of nickel wire subject to combined torsional and longitudinal stresses. The wire under examination was first demagnetized by successive reversals of a current of gradually diminishing strength. A definite load was then applied, and the wire twisted through a definite angle by means of the twisting apparatus described in the preceding paper. The wire was then subjected to magnetizing currents of gradually increasing strengths, and the amount of induced magnetism measured by means of the deflection of the contiguous magnetometer mirror. The details of the arrangement and method are as follows.

The magnetizing current was obtained from 14 large Daniell cells, and the strength was varied continuously by means of a liquid slide. A commutator, consisting of rocker and mercury pools, was included in the circuit, so as to facilitate the reversing of the diminishing current which was necessary for demagnetizing the wire in position. The reversals were continued till the wire became magnetically neutral.

There was also an arrangement for compensating the direct electromagnetic action of the magnetizing coil—a real necessity in such experiments with nickel, because of the comparatively small susceptibility of this metal. The arrangement consisted of a ring with a few coils of wire wound round it. This ring mounted at the proper height on a wooden stand, which could be moved along a groove cut in the plank on which the magnetometer rested, was set in front of the magnetometer. The magnetizing current was led through this small coil, whose distance from the magnetometer was adjusted, so as to compensate the effect due to the solenoid. It was very difficult to set the ring exactly at the desired position, so that it was generally necessary to apply small corrections to the readings obtained.

In the first experiment a nickel wire 1 mm. in diameter and 40 cms. long was previously heated red hot. This was placed in the magnetizing solenoid and demagnetized without at first any application of longitudinal stress. The strength of the magnetizing field was then gradually increased till it attained the value of 29 C. G. S units, magnetometer readings being taken at intervals. The residual magnetism was determined as the magnetizing current was gradually reduced from its maximum value to zero. The normal curve of magnetization thus obtained is represented in Fig. I. *(a)*. After this, the wire was demagnetized by reversals, and twisted through an angle of 40°, so as to give a twist of 1° per cm. Under these slightly altered conditions, the experiment was repeated. Up to the strength of field $\mathfrak{H} = 4.2$, things were sensibly the same as in the former case. But as $\mathfrak{H}$ was raised to 5.2, a very sudden change occurred in the magnetization. The magnetometer reading rose abruptly from 8 to 97 ; and then as $\mathfrak{H}$ was still further increased to 6.1, the reading rose to 144. But after $\mathfrak{H}$ attained the value of 9.1, the rate of increase of induced magnetism per unit of the increase of the magnetizing field suddenly diminished, almost immediately falling off to a value which remained nearly constant for higher fields. That is, the magnetization curve at these higher fields becomes almost a straight line. Thus it appears that twisted nickel has an enormous *differential susceptibility* ($d\mathfrak{I}/d\mathfrak{H}$)* within a certain quite limited range of field, and that for fields outside the lower and higher limits the differential susceptibility is comparatively small, and at high fields practically constant. Curve Fig. I *(b)* represents the case just discussed. No peculiar character as compared with the normal curve *(a)* is seen at a glance. The "wendepunkt" or point of maximum susceptibility occurs in a smaller field for the twisted nickel than for the untwisted. The value of the maximum susceptibility is also greater for the twisted nickel. But when once the "wendepunkt" for the twisted nickel is passed, the differential susceptibility rapidly diminishes in such a

* This term is suggested by Dr. C. G. Knott. Susceptibility always means the ratio of the magnetization to the magnetizing force that is producing it; and it is convenient, especially in discussing the peculiarities of nickel, to have a simple but suggestive phrase for "the rate of change of magnetization per unit increase of field."

way that above a certain field (27.6) the twisted nickel has a smaller susceptibility than the untwisted. This is shown by the curve *(b)* crossing the curve *(a)* at this particular field.

The wire was now demagnetized, and twisted through an angle of 80°, that is 2° per cm. The magnetization curve obtained in this state is shown graphically in Fig. I *(c)*. The chief characteristics remain the same as for *(b)*; but the "wendepunkt" occurs sooner, and the curve rises more abruptly to this point than for the case of smaller twist. Another thing to be remarked is the increase of residual magnetism. For the untwisted nickel, the ratio of the residual to the induced magnetism is .75 for $\mathfrak{H} = 29$; for the wire twisted through an angle of 1° per cm. it is .95; and for the twist of 2° per cm., it is .96. For a twist of 120° or 3° per cm. these characteristics acquire the maximum condition; the curves of magnetization rising less abruptly, and the maximum susceptibility as shown by the "wendepunkt" becoming smaller, when the twist is increased to 4°.5 per cm. A twist of 9° per cm. still further diminishes this abruptness; but the recovery of the wire towards the original magnetic condition in the untwisted state is very slow. Indeed at all twists the magnetization curve presents much the same characteristics. The general results of these experiments are as follows. Nickel wire twisted under no load acquires its maximum susceptibility in a particular field of force, which is a function of the twist, and is a minimum for a twist of 3° or 4° per cm. In other words, if we draw a line from the origin to the "wendepunkt," the line (the tangent of whose inclination gives the maximum susceptibility) is, so to speak, gradually deflected to higher inclinations as the wire is twisted up to 3° or 4° per cm. It then begins to move back again in the direction of its original position, but very slowly, so that there is not very much difference in the curves for highly twisted wires and a moderately twisted wire. The maximum value of the differential susceptibility is very great for twisted wire, and is greatest for the twisted wire which has the greatest maximum susceptibility. After passing the "wendepunkt," the magnetization curve becomes almost straight, the differential susceptibility becoming very small and of such a nature as to cause the nickel always to cut the curve for untwisted nickel. This point of intersection occurs sooner for higher twists. And finally the amount of residual magnetism is enormously increased by twisting the wire even through a small angle.

In the experiments now to be described, the wire was subjected to extra loads. It was necessary, however, to take a new wire cut of course from the same specimen, and treated preliminarily as the first piece was.

The first extra load used was nearly 1 kg.; and with this load exactly the same series of experiments was gone through as in the previous case. In Fig. 2, the curves of magnetization are shown graphically. They are very similar to the curves of Fig. 1 ; only in this case it was not possible with the strength of field used to get the curves for the twisted nickels to intersect the curve for the untwisted nickel. In all probability, however, the crossing will occur for high enough fields.

It was natural to enquire, here, as to the after effect of the twist. It is known that, because of the elastic after-strain, the wire does not return exactly to its former position when the twisting stress is relieved. It seemed likely that something analogous would occur in reference to the magnetic characteristics of the wire. Accordingly the wire, after it had been twisted, was allowed to hang freely under the action of the load ; and under these conditions, the magnetization curve was obtained. Comparing it with the first curve, we see that there is distinct evidence of a change in the magnetic properties of the wire. The susceptibility of the wire that has been twisted is in general diminished to a slight extent, although in one or two places, it is increased.

Further experiments made by subjecting the wire to longitudinal stresses of 5.14 and 10.14 kgs. gave the same general results. The curves are shown in Fig. 3 and Fig. 4 respectively. All the curious characteristics are the same as before. Comparing the curves for untwisted with the curves for twisted wire, we see how marked is the difference between these two conditions, and especially when the wire is subjected to considerable longitudinal stresses. The curves show very readily that the magnetic susceptibility for a field of 27 units of the untwisted wire with a load of 5 kgs. is only one half the susceptibility for the same with a twist of 1° per cm. But judging from the march of the curve, we may safely conclude that the susceptibility of the untwisted wire will become greater than that of the twisted wire, when the strength of the field is sufficiently increased. With a load of 10 kgs., the susceptibility of the wire which has suffered a torsion of 3° per cm. is 3 times as great as that of the untwisted wire even at the field of 27 units.

Another thing to be noticed is the receding of the "wendepunkt" for the twisted wire under heavy load. This point tends to move gradually towards the right as the load is increased at constant twist. This is not so well marked in the first two experiments, but is quite apparent when the longitudinal stress amounts to 5 or 10 kgs. Thus for the unloaded wire with a twist of 1° per cm., the "wendepunkt" lies at $\mathfrak{H} = 6.3$, while for the wire under the longitudinal stress of 5 kgs., it occurs at $\mathfrak{H} = 12$. Similarly for a wire with a twist of 3° per cm., the "wendepunkt" occurs at $\mathfrak{H} = 4.3$ for the unloaded, and at $\mathfrak{H} = 11$ for the loaded wire. This is still more marked when the wire is loaded with 10 kgs.

The following tables contain the observed numbers :—

I. W = 2.5 kgs. cm².

$\mathfrak{H}$	$\mathfrak{I}$ $\tau=0$.	$\mathfrak{I}$ $\tau=1^\circ$ per cm.	$\mathfrak{I}$ $\tau=2^\circ$ per cm.	$\mathfrak{I}$ $\tau=3^\circ$ per cm.	$\mathfrak{I}$ $\tau=4^\circ.5$ per cm.	$\mathfrak{I}$ $\tau=9^\circ$ per cm
2.2	10.1	4.3	1.8	2.0	2.0	4.0
3.2	...	...	...	47.4	9.7	11.2
3.4	...	...	69.5	...	...	...
4.2	22.6	13.2	238.2	243.6	135.1	164.8
5.2	36.5	160.2	282.3	285.9	279.0	260.5
6.1	70.3	238.3	289.7	293.0	288.9	276.4
7.1	109.4	269.6	295.2	295.8	...	...
8.1	131.7	277.7	297.5	297.7	293.5	285.1
10.1	170.9	286.3	301.1	300.3	...	...
11.9	200.6	291.4	303.3	301.8	298.0	290.4
13.9	220.8	295.7	304.8	...	...	...
15.8	236.8	299.3	305.9	304.4	300.8	293.2
19.6	272.9	304.3	307.7	305.9	302.3	294.4
23.5	295.4	308.9	309.4	...	303.4	295.7
29.2	316.1	313.0	311.7	307.6	304.6	297.3
23.5	310.7	310.4	309.5	306.4	304.1	296.8
15.8	298.2	306.1	307.7	305.7	303.9	296.5
8.1	278.0	299.6	306.4	305.5	301.6	294.9
0	237.9	290.2	300.0	298.0	293.2	286.1

II. W = 145 kgs. cm².

$\mathfrak{H}$	$\mathfrak{I}$ $\tau=0^\circ$ per cm.	$\mathfrak{I}$ $\tau=1^\circ$ per cm.	$\mathfrak{I}$ $\tau=3^\circ$ per cm.	$\mathfrak{I}$ $\tau=9^\circ$ per cm.	$\mathfrak{I}$ $\tau=15^\circ$ per cm.	$\mathfrak{I}$ (Untwisted.)
2.2	6.3	7.3	4.6	3.0	2.3	3.3
3.2	8.7	16.2	9.9	8.6	3.6	5.3
4.2	12.4	32.5	196.4	24.8	17.3	7.9
5.2	23.1	86.0	229.4	55.4	49.2	19.3
6.1	40.3	192.4	247.2	121.1	109.4	35.6
7.1	58.9	209.7	256.4	229.0	206.3	50.3
8.1	77.1	216.5	264.0	249.0	242.6	67.7
10.0	112.2	226.5	270.4	256.6	255.1	101.0
11.9	133.7	233.3	273.9	261.4	260.2	135.6
15.8	165.0	239.3	277.2	267.3	264.5	178.5
19.6	196.2	252.9	278.9	270.4	267.3	201.6
23.5	219.5	262.4	280.0	272.3	269.4	218.5
27·3	236.0	269.3	280.8	273.9	270.7	229.0
23.5	231.0	267.3	...	...	...	224.7
15.8	216.8	262.0	...	...	...	214.5
8.1	196.7	255.8	278.9	270.1	267.3	201.8
0	167.5	245.9	272.7	263.7	260.7	181.5

III. W = 655 kgs. cm².

ℌ	ℑ τ=0.	ℑ τ=1° per cm.	ℑ τ=3° per cm.	ℑ τ=5°.5 per cm.	ℑ τ=9° per cm.	ℑ (Untwisted.)
2.2	3.8	3.0	0.5	1.7	1.0	4.0
3.1	6.1	4.8	0.8	4.5	2.6	6.1
4.2	9.2	5.9	2.5	6.3	4.8	8.3
5.2	11.6	7.6	3.8	7.4	6.4	10.6
6.1	15.3	9.6	4.8	9.2	7.6	11.7
7.1	18.3	16.0	6.8	12.0	8.7	13.0
8.1	23.4	30.5	11.4	14.5	11.9	15.2
9.0	27.9	56.9	29.7	19.1	13.7	17.0
10.0	31.0	95.2	150.1	50.0	18.8	20.1
11.0	...	125.2	184.6	127.2	25.1	22.9
11.9	34.3	140.3	199.0	196.0	44.2	25.1
12.9	...	149.0	204.1	203.0	135.8	28.1
13.9	40.6	156.1	208.9	206.7	184.1	35.0
15.8	47.4	165.2	213.5	211.4	198.7	41.6
17.7	57.3	171.9	217.8	214.5	204.1	48.3
19.6	67.3	178.2	219.5	218.0	207.2	57.3
23.5	80.4	185.8	222.4	221.3	212.2	70.3
27.3	92.7	190.2	224.9	224.2	217.5	81.2
23.5	85.5	188.8	224.4	222.8	215.2	77.7
15.8	74.4	185.3	222.6	220.1	212.9	66.0
8.1	58.6	180.2	221.4	218.1	210.7	53.9
4.2	51.2	177.2	220.8	216.3	208.9	47.9
0	42.2	173.6	217.8	214.2	205.9	39.6

IV. W = 1290 kgs. cm².

ℌ	ℑ τ=0.	ℑ τ=1° per cm.	ℑ τ=3° per cm.	ℑ τ=5°.5 per cm.	ℑ τ=9° per cm.	ℑ (Untwisted.)
2.2	2.0	3.3	0.8	0.8	0.5	3.5
4.2	6.1	7.4	3.6	3.3	1.8	6.6
6.1	8.7	11.2	5.9	5.0	4.5	9.6
8.1	11.7	15.2	8.6	8.3	7.1	12.2
10.0	14.9	19.6	12.9	12.5	9.1	14.9
11.9	18.2	24.3	19.8	21.5	11.2	17.7
13.9	21.5	29.7	162.5	74.3	13.0	20.5
15.8	25.1	34.7	170.4	163.4	22.1	24.8
17.7	28.4	41.3	173.3	169.0	134.0	27.2
19.6	31.7	48.5	175.4	173.3	151.0	30.0
21.5	35.1	58.1	177.2	176.1	157.2	32.7
23.5	38.4	65.5	179.0	178.0	161.7	35.3
27.3	45.0	82.8	181.8	182.7	168.3	41.6
23.5	39.6	78.9	...	181.3	165.8	36.5
15.8	28.1	69.3	176.7	176.9	161.7	25.9
8.1	16.3	59.4	172.1	...	155.8	14.9
4.2	9.2	54.1	170.0	171.6	152.1	8.3
0	3.3	48.7	167.1	165.3	148.5	3.3

Reviewing the results of these experiments we see that twisting produces many singular effects on the magnetic properties of nickel. In the first place, maximum susceptibility occurs, for the twisted wire, at lower values of the magnetizing force than for the untwisted wire. The amount of twist which must be applied to obtain the maximum susceptibility in the weakest field is about 3° per cm. For higher twists, the "wendepunkt" occurs at the higher values of the field. The critical value of twist is nearly constant for all values of longitudinal stress. Also, the wire which, twisted to this critical amount, gives the greatest maximum susceptibility, gives at the same twist the greatest maximum differential susceptibility—in other words the curve rises most abruptly to its turning point. The field for maximum differential susceptibility is very slightly smaller than the field for maximum susceptibility. As the latter is passed, the differential susceptibility diminishes markedly in value and remains pretty constant in the higher fields. Ultimately the magnetic susceptibility of the twisted nickel becomes less than that of the normal wire, the curves crossing each other in high magnetic fields. Again the field for maximum susceptibility increases with load; but the maximum susceptibility itself diminishes. Also the susceptibility in fields of moderate strength is more sensitive to twisting for the greater loads. This effect of load is more marked with regard to the residual magnetism. Thus with a load of 10 kgs. in a field of 27, a wire with a twist of 3° per cm. shows 50 times as much residual magnetism as it did in the untwisted condition. Finally the wire released from torsion behaves in a different way from the normal one, the magnetic effect of stress outliving the removal of it.

II. The effect of combined longitudinal and torsional stresses on the retentiveness of nickel wire.

After the preceding experiments were finished, I determined to examine the residual magnetism of the nickel wire under the action of two stresses, especially at the point where the susceptibility suddenly increases. The experiments were conducted in very much the same way as before. A nickel wire 40 cms. long and 1 mm. thick was placed in a double solenoid, the second solenoid serving to neutralize the earth's field. After the wire was demagnetized, magnetizing forces of gradually increasing magnitudes were applied and removed. The residual magnetism was then measured. All the applications and removal of the magnetizing force were conducted very gradually and readings were taken at each step.

The wire was treated exactly as before as regards both the longitudinal and the torsional stresses. The observations for each of the combinations of longitudinal and torsional stresses are given in the following tables, which also contain the ratios of the temporary and residual magnetisms.

I. $W = 2.5$ kgs. cm^2.

	$\tau=0$			$\tau=0.5°$ per cm.			$\tau=1°.5$ cm.		
$\mathfrak{H}$	Temp. Mag.	Resid. Mag.	Resid./Temp.	Temp. Mag.	Resid. Mag.	Resid./Temp.	Temp. Mag.	Resid. Mag.	Resid./Temp.
1.9	8.3	1.5	...	3.3	.3	...	3.3	1.7	...
3.9	20.6	5.9	.29	16.5	7.3	.44	154.1	150.2	.97
4.8	..	...	...	28.1	15.8	.56	219.5	214.5	.98
5.8	57.8	34.7	.60	67.3	52.8	.78	246.8	239.9	.97
7.7	116.3	83.2	.72	193.1	172.1	.89	260.7	252.5	.97
9.7	150.2	110.9	.74	221.1	196.4	.89	269.4	258.4	.96
11.6	181.5	133.0	.74	234.3	205.3	.88	275.6	261.2	.95
13.5	206.3	150.6	.73	247.5	215.5	.87	...	...	...
15.4	229.4	167.6	.73	259.1	220.6	.85	284.0	266.0	.94
17.4	249.5	181.5	.73	267.6	226.1	.84	...	...	...
19.3	261.7	188.9	.73	276.8	230.8	.83	291.7	268.0	.92
23.2	290.4	209.9	.72	290.7	237.6	.82	297.0	269.6	.91
27.0	307.6	219.5	.71	300.8	240.9	.80	303.3	271.4	.90

	τ=4°.5 per cm.			τ=9°.0 per cm.			Untwisted.		
$\mathfrak{H}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$
1.9	5.0	2.6	.53	3.3	1.2	...	8.3	4.5	...
3.9	84.8	80.9	.95	52.0	48.2	.93	21.5	13.5	.62
4.8	200.8	194.7	.97	146.2	140.7	.96	...	...	...
5.8	233.1	226.5	.97	222.8	217.8	.98	45.5	34.2	.75
7.7	255.3	249.8	.97	247.5	240.7	.96	104.6	87.9	.84
9.7	267.3	256.6	.96	255.8	247.5	.96	150.2	128.7	.86
11.6	272.3	260.4	.96	260.7	250.8	·96	169.2	143.9	.85
15.4	282.2	262.7	.93	267.3	253.4	.95	198.0	163.4	.83
19.3	287.4	264.2	.92	272.9	255.8	.94	216.2	175.9	.81
23.2	292.1	266.1	.91	277.2	257.4	.93	231.0	183.5	.79
27.0	296.1	267.0	.90	280.5	257.9	.92	243.7	189.8	.78

II. W = 145 kgs. cm^2.

	τ=0.			τ=0°.5 per cm.			τ=1°.5 per cm.		
$\mathfrak{H}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$
1.9	4.0	...	...	4.0	0	...	2.3	0	...
3.9	9.7	...	...	9.1	.7	...	4.5	.8	...
5.8	18.3	4.6	.25	26.4	14.4	.54	16.2	10.2	.63
6.8	...	...	...	38.1	24.1	.63	51.5	44.6	.86
7.7	30.4	12.4	.41	54.5	39.3	.72	177.2	170.8	.96
9.7	54.3	30.5	.56	98.8	78.0	.79	229.4	221.3	.96
11.6	88.1	58.1	.66	152.0	127.9	.84	242.1	232.3	.96
13.5	120·1	85.0	.71	173.6	147.5	.85	250.0	238.6	.95
15.4	143.2	102.8	.72	187.8	158.2	.84	254.6	242.1	.95
17.4	159.4	113.2	.71	200.1	166.2	.83	...	...	...
19.3	174.2	124.1	.71	209.9	172.9	.82	262.8	246.5	.94
23.2	...	...	...	224.9	182.2	.80	...	...	...
27.0	212.9	146.2	.68	237.6	189.1	.79	272.3	251.6	.92

$\tau=3^{\circ}.0$ per cm. $\tau=4^{\circ}.5$ per cm. $\tau=9^{\circ}$ per cm.

$\mathfrak{H}$	Temp. Mag. ($\tau=3^{\circ}.0$)	Resid. Mag. ($\tau=3^{\circ}.0$)	$\frac{\text{Resid.}}{\text{Temp.}}$ ($\tau=3^{\circ}.0$)	Temp. Mag. ($\tau=4^{\circ}.5$)	Resid. Mag. ($\tau=4^{\circ}.5$)	$\frac{\text{Resid.}}{\text{Temp}}$ ($\tau=4^{\circ}.5$)	Temp. Mag. ($\tau=9^{\circ}$)	Resid. Mag. ($\tau=9^{\circ}$)	$\frac{\text{Resid.}}{\text{Temp.}}$ ($\tau=9^{\circ}$)
1.9	1.2	0	...	1.2	0	...	1.2	...	...
3.9	2.5	0	...	2.5	0	...	2.8	.3	...
5.8	3.8		...	5.9	2.1	.36	5.1	1.7	.32
6.8	184.8	181.5	.98	46.5	42.6	.92	21.1	17.0	·80
7.7	219.6	216.2	.98	239.6	236.0	.985	93.9	90.8	.98
9.7	259.9	255.8	.98	258.2	254.1	.98	242.2	238.6	.98
11.6	266.1	261.5	.98	264.2	259.7	.98	253.9	249.0	.98
13.5	...	...	..	268.1	262.8	.98	259.1	253.9	.98
15.4	273.1	266.3	.98	270.8	264.8	.98	262.0	255.8	.97
17.4	...	...	...	..	...	...	...	...	...
19.3	277.2	268.3	.97	274.9	266.0	.97	266.8	258.4	.97
23.2	279.5	269.3	.96	...	...	...	...	...	...
27.0	282.2	269.6	.96	279.2	266.8	.96	272.3	259.5	.95

III. W = 1040 kgs. cm^2

$\tau=0^{\circ}$ $\tau=1^{\circ}.5$ per cm.

$\mathfrak{H}$	Temp. Mag. ($\tau=0^{\circ}$)	Resid. Mag. ($\tau=0^{\circ}$)	$\frac{\text{Resid.}}{\text{Temp.}}$ ($\tau=0^{\circ}$)	Temp. Mag. ($\tau=1^{\circ}.5$)	Resid. Mag. ($\tau=1^{\circ}.5$)	$\frac{\text{Resid.}}{\text{Temp.}}$ ($\tau=1^{\circ}.5$)
1.9	1.5	...	...	3.3	.7	...
3.9	4.1	.3	...	8.7	4.3	...
5.8	8.1	.5	...	15.3	8.7	.57
7.7	11.4	.8	.07	29.0	19.5	.67
9.7	15.2	1.7 ?	.11 ?	63.5	51.0	.80
11.6	19.5	2.0	.10	96.7	82.2	.85
13.5	22.4	2.3	.11	111.4	94.7	.85
15.4	26.2	3.3	.13	122.4	104.0	.85
19.3	33.7	4.1	.12	136.0	115.5	.85
23.2	41.4	5.0	.12	148.0	121.1	.82
27.0	47.9	5.9	.12	156.9	124.1	.79

	τ=4°.5 per cm.			τ=9° per cm.		
$\mathfrak{H}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$	Temp. Mag.	Resid. Mag.	$\frac{\text{Resid.}}{\text{Temp.}}$
1.9	1.2	0	...	2.6	0	...
3.9	5.3	1.0	...	5.4	1.0	.18
5.8	11.4	4 6	.41	...	...	...
7.7	22.8	13.7	.60	20.0	11.9	.59
9.7	70.1	58.7	.84	48.2	36.0	.75
11.6	129.4	114.7	.88	98.0	83.5	.85
13.5	139.1	124.9	.90	128.4	114.3	.89
15.4	146.0	128.4	.88	138.8	120.8	.87
19 3	156.1	134.0	.86	150.8	128.7	.85
23.2	166.2	137.9	.84	159.7	133.0	.83
27.0	173.0	141.9	.82	168.3	138.6	.80

The curves showing the temporary and residual magnetisms are given in Figs. 5_a, 6_a, 7_a, and Figs. 5_b, 6_b, 7_b; and the curves showing the ratio of the residual to the induced magnetism in Figs. 5_c, 6_c, and 7_c.

The inspection of these figures will show how curious a change is produced in the residual magnetism of twisted nickel wire, when the magnetizing force is that which corresponds to maximum susceptibility. In some cases, the amount of residual magnetism is indeed enormous, reaching to .98 of the induced magnetism.

Examining the curves obtained for the wire which was only subject to the action of its own weight and the twisting rod, we see that for the untwisted wire, the ratio of residual to temporary magnetism increases to a maximum at about field 10. Its value is then .74. At higher fields, this ratio gradually diminishes. The curve representing these ratios is shown in Fig. 5_c. But when the wire is twisted only through an angle of 0°.5 per cm., the curves of induced and residual magnetisms are quite different from those of the untwisted wire. The ratio of residual to temporary magnetisms increases up to

.89 instead of .74. However, this large retentiveness occurs just at the field where the susceptibility is at its maximum. The rate at which this ratio grows with the field is almost uniform till the maximum is reached, if we leave out of account the observations at very low fields which cannot in the circumstances be regarded as at all accurate. The curves in Fig. 5_c are therefore straight up to the maximum. For the twisted wire the maximum is passed very abruptly; and for the rest of their course all the curves are approximately straight lines.

With a twist of 1°.5 per cm, the amount of residual magnetism increases still more; and at the maximum point which again occurs near the wendepunkt, the ratio of the residual to the temporary attains the value of .98. It is indeed wonderful what a great effect simple twisting of nickel produces upon its retentiveness. The approach to the maximum ratio takes place more suddenly in this than in the previous case, the curve sloping more steeply. There is nothing singular after the maximum is passed, but the rate of fall for higher fields becomes distinctly less for the larger twist. When the twist is increased to 4°.5 or 9° per cm, there is a distinct tendency in the curve to return to its former state. Thus the slope gradually becomes less steep, and the maximum occurs at higher fields. But the ratio of the residual to the temporary magnetism still keeps to its late value. Again the rate of fall of the ratio after the maximum is reached gradually lessens as the twist is increased.

From these experiments, we gather that twist applied to nickel wire increases its residual magnetism, which attains a maximum in the field corresponding to the maximum susceptibility. For moderate twists this maximum residual falls short of the temporary magnetism by only 2 per cent. The sooner the "wendepunkt" occurs, the more rapid is the rate of increase of the residual magnetism; and consequently, there exists a twist for which the maximum slope of the percentage curve attains a greatest value. The rate at which the residual magnetism falls off in higher fields is diminished as the twist is increased.

The next series of experiments related to the combined effect of torsional and longitudinal stresses. For this purpose, a new wire properly prepared was loaded with 1.14 kgs. The normal curve (Fig. 6) show a slight decrease of retentiveness; and the curve obtained for the twist of 0°.5 per cm. does not show those curious characteristics of the twisted nickel. The retentiveness, however, is greatly increased, and at its maximum, the residual magnetism is .85 of the induced. But when the twist is increased to 1°.5, all the curious properties of twisted nickel already mentioned become apparent and confirm the results already obtained for the unloaded wire. In this case the maximum ratio of the residual to the induced magnetism attains the enormous value of .985. The greatest maximum slope in the ratio curves again occurs for the value of twist for which the "wendepunkt" occurs sooner. This is for a twist of nearly 3° per cm. As may be seen from the experiments on the relation of $\mathfrak{J}$ and $\mathfrak{H}$, this is the twist which gives the maximum differential susceptibility. Hence it would appear that the twist of about 3° per cm. has a certain critical significance in the relations of twist to magnetization for the specimens of nickel wire used.

When the load is increased to 3.14 kgs., the maximum ratio of residual to temporary magnetism diminishes to .97, but the general characteristics still remain the same.

The experiments made on the wire which was loaded with a weight of 8.14 kgs. also brings out clearly the effect of twist on the retentiveness of nickel. The residual magnetism for no twist is indeed very small with such a large load; but merely twisting the wire through 1°.5 per cm. is sufficient to increase the maximum retentiveness more than 6 times for a field of 27, although the absolute value of the residual magnetism falls far short of the values obtained for small longitudinal stresses. The maximum value of the ratio of the residual to induced magnetism is .90 for a twist of 4°.5 per cen. These phenomena are represented in Fig. 7_a, 7_b, 7_c.

All these curious properties of the twisted nickel must be accounted for by the change of molecular structure caused by the torsional stresses. But as we know nothing regarding molecular arrangements, we can make no definite assertion how the change takes place. We may however conceive the wire in the normal state as consisting of an assemblage of rows of molecules arranged in a straight line along the length of the wire. On twisting the wire, these rows or filaments of molecules will no longer be straight, but will become a spiral. Since all such molecular filaments in the wire suffer similar distortion, the axes of the molecules in the unmagnetized nickel will be indifferently placed in all directions either in the normal or the twisted wire. Now if the wire is magnetized longitudinally, the magnetizing force will be parallel to the molecular filaments in the untwisted wire, but in the twisted wire the corresponding molecular filaments will no longer be parallel to the magnetizing force. Such considerations would lead us to expect distinct differences in the curves of magnetization for the two states of nickel.

If, according to Weber's theory, the application of a magnetizing force tends to turn the axes of the molecules in one direction, the results of my experiments show that the twist applied to the wire makes the molecules turn more easily. There also exists a critical value of twist, beyond or below which the molecules turn with less ease. This twist is about 3° per cm. in the wire experimented. But in spite of the ease of the molecules in turning, they seem to be unable to turn beyond a certain angle, so that when once the sudden rotation of molecules takes place, the rate of turning becomes very small. It also appears that when the sudden turning of the molecules takes place, the tendency of the molecules to revert to their former positions is very small, the retentiveness being large

All this is a mere hypothesis, since we know nothing of the original arrangement of the molecules, and far less of how they are changed. If however we assume Weber's theory, we may regard the curious phenomena presented by twisted nickel as being accompanied by such motions of the magnetic molecules as have just been described.

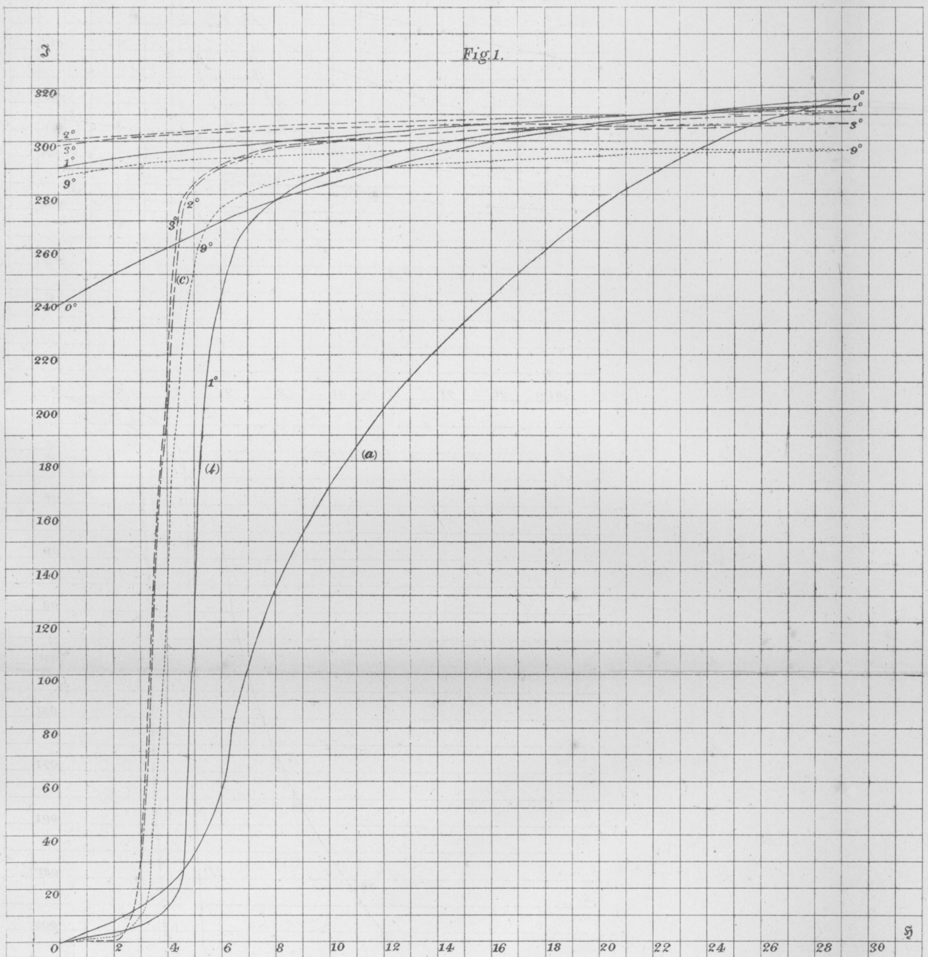


Fig. 1.
ℑ
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
ℌ
0°
1°
2°
3°
9°
(a)
(c)
(4)

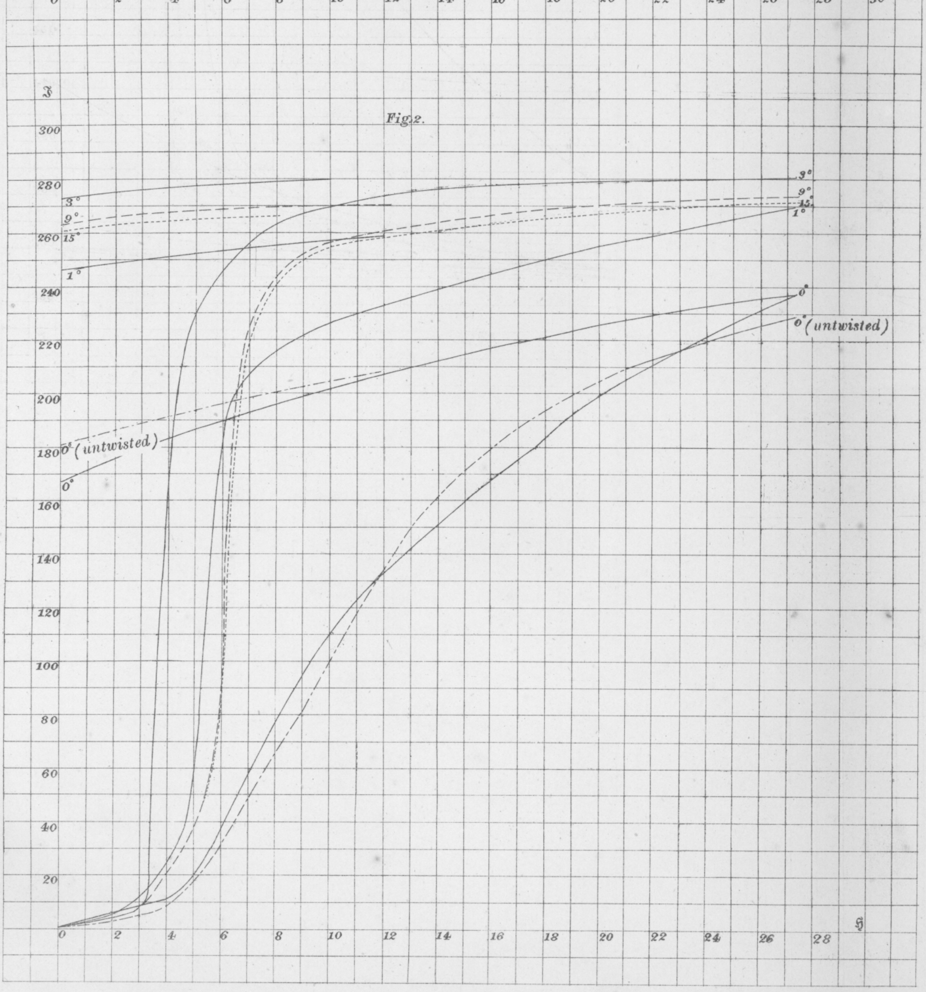
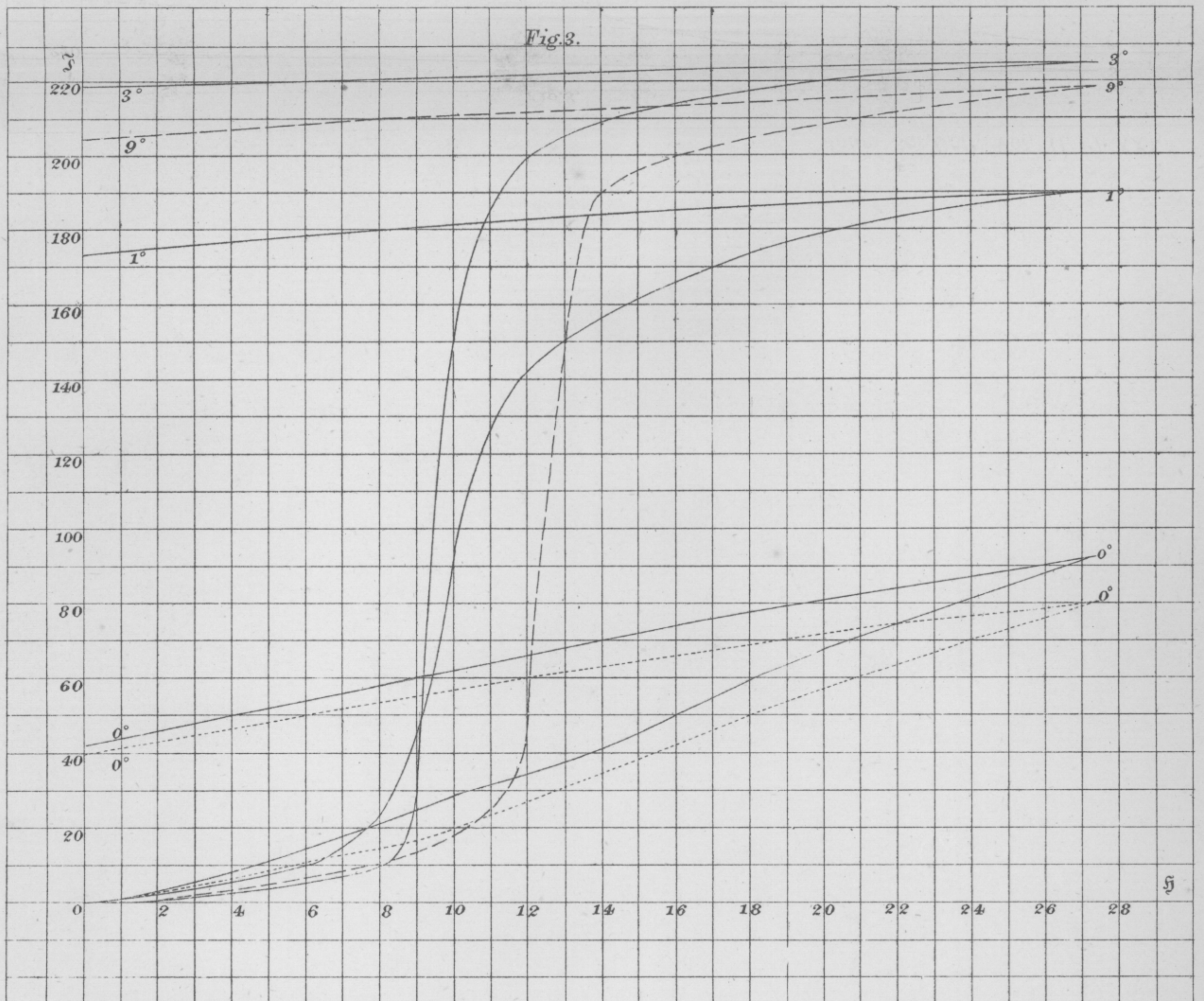


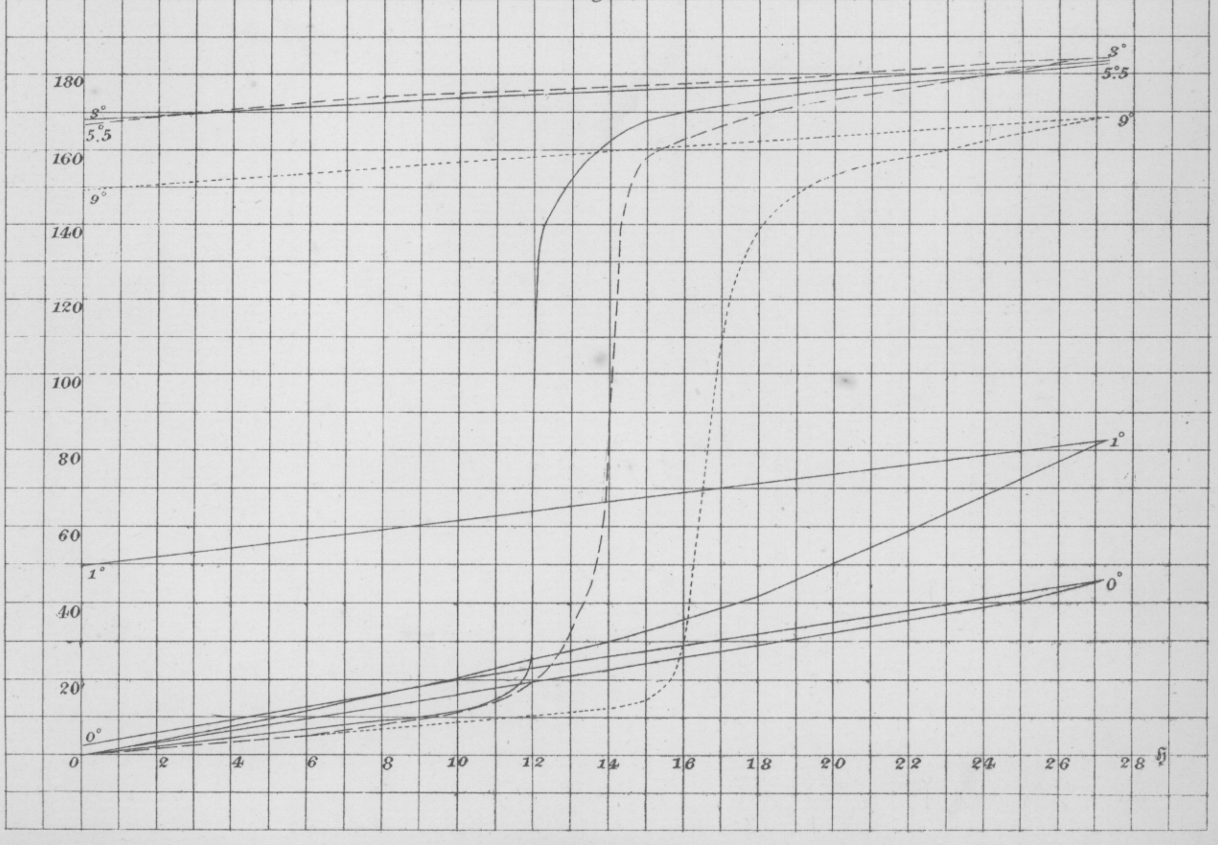
Fig. 2.
ℑ
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
ℌ
3°
9°
15°
1°
0°
0° (untwisted)

Fig. 3.

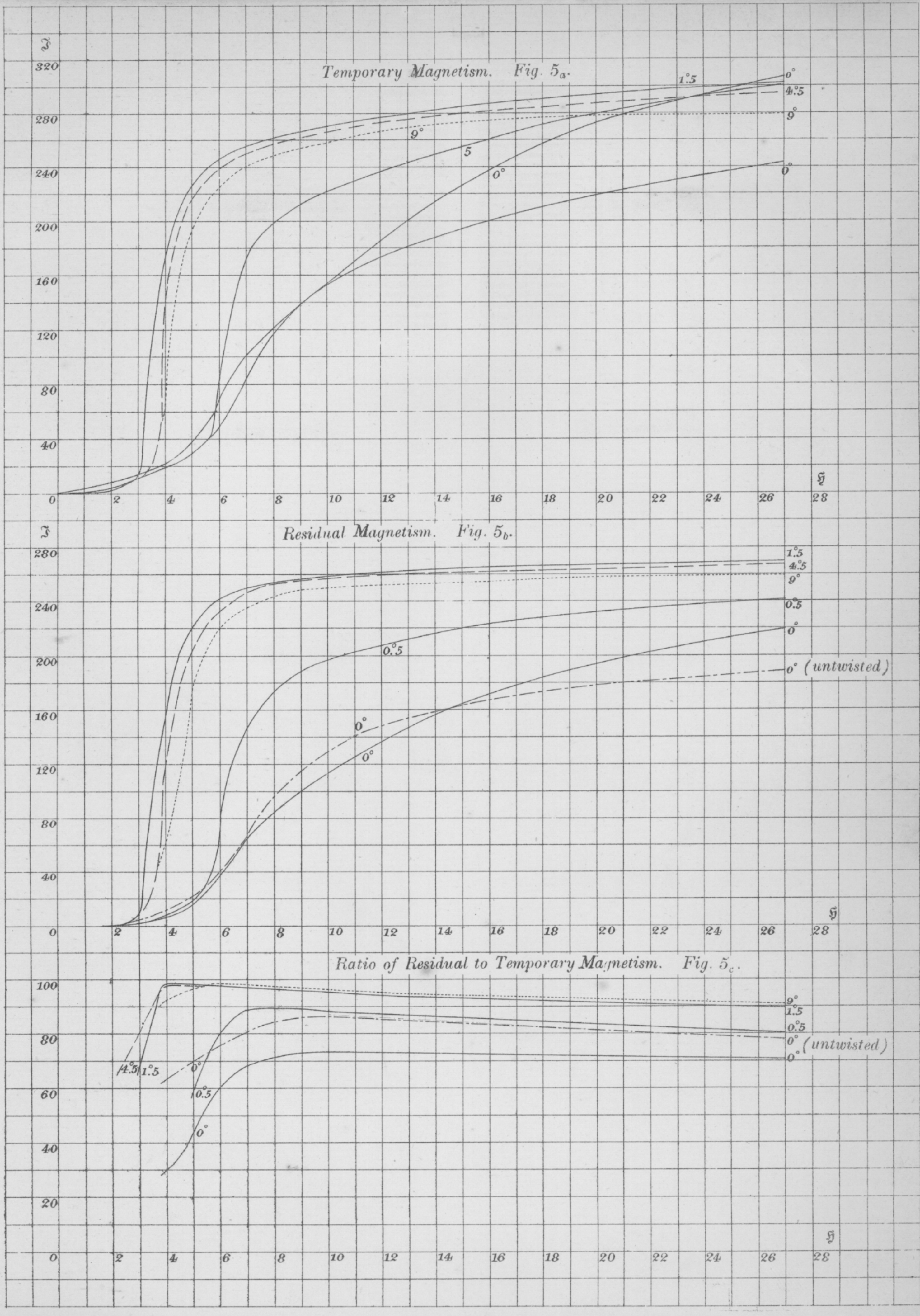


ℑ
220
200
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
ℌ
3°
9°
1°
0°

Fig. 4.



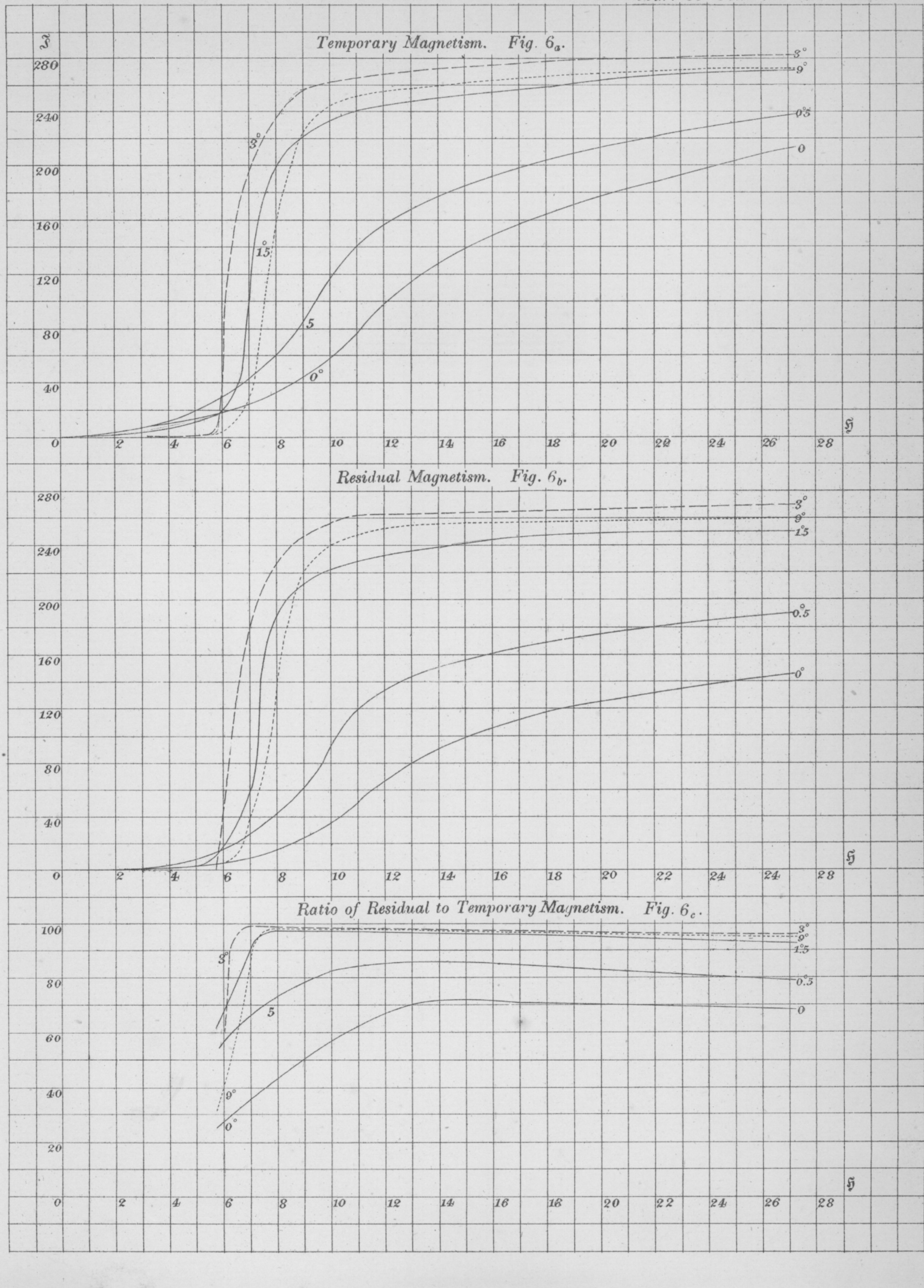
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
ℌ
3°
5.5
5°.5
9°
1°
0°

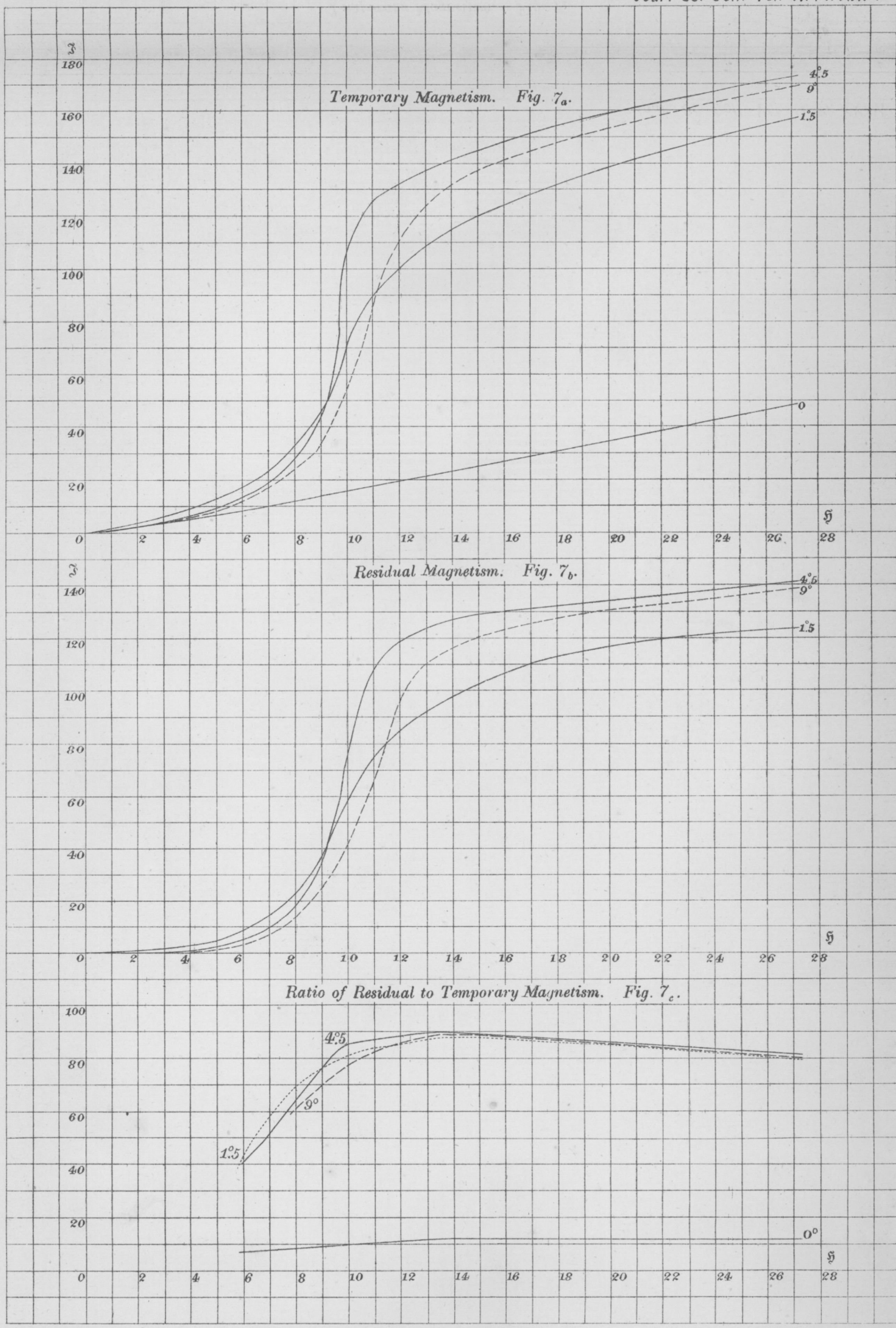


Temporary Magnetism. Fig. 5_a.

Residual Magnetism. Fig. 5_b.

Ratio of Residual to Temporary Magnetism. Fig. 5_c.


Temporary Magnetism. Fig. 6a.
Residual Magnetism. Fig. 6b.
Ratio of Residual to Temporary Magnetism. Fig. 6c.
ℑ
ℌ
0
40
80
120
160
200
240
280
20
60
100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
0°
0.5
1.5
3°
9°
5


Temporary Magnetism. Fig. 7a.
Residual Magnetism. Fig. 7b.
Ratio of Residual to Temporary Magnetism. Fig. 7c.
4°.5
9°
1°.5
0
0°
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28