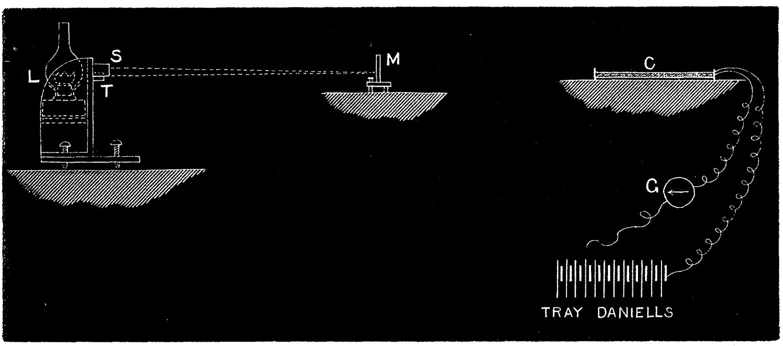
II. "On the Magnetisation of Steel, Cast Iron, and Soft Iron" (being the investigation for which the Watt Prize of 1884 was awarded by the Senate of the University of Glasgow). By JOHN W. GEMMELL. Communicated by Sir WILLIAM THOMSON, Kt., LL.D., F.R.S. Received October 31, 1885.

The experiments, of which the following is a description, with their results, were performed in the Physical Laboratory of the University of Glasgow, and had for their object the finding of the difference between specimens of iron and of steel with respect to the intensities of their total and residual magnetisation due to different degrees of magnetising force.

The specimens consisted of (1) wires of "soft Scotch" iron, of "common wire," of "charcoal iron," and of "soft steel;" and (2) bars of cast iron and of malleable iron. The wires were 31 cm. long and 0·5 cm. in diameter, and weighed respectively 39·85, 39·9, 41·5, and 38·5 grams. The bars, two of which were of cast iron procured from different foundries, were 15·25 cm. long, and of section 1 cm. square. The cast iron bars weighed each 114 grams, and the malleable iron bar 125 grams.

The arrangement of the apparatus employed in the investigation is shown in the accompanying diagram (fig. 1). The magnetising coil,

FIG. 1.



represented at C, was 40 cm. in length, and consisted of three layers of 600 turns each of silk-covered copper wire, wound on a brass tube of the same internal diameter as the wires. It was placed on a convenient stand with its axis horizontal and at right angles to the magnetic meridian. For the experiments on the bars the coil was 21 cm. in length, and consisted of five layers of 155 turns each of insulated

copper wire wound on a copper case of square section just fitting the bars.

The magnetising current passing through the coil was obtained from a battery of Thomson's tray Daniells, by means of which any desired current above 0·25 of an ampère could be employed. To obtain currents ranging from 0 to the minimum (0·25) to be got by the battery, a resistance-box, capable of inserting any resistance up to 10,000 ohms, was placed in the circuit with a single cell.

The strength of the current was measured by one of Sir William Thomson's graded galvanometers, represented at G, a full description of which will be found in Mr. Andrew Gray's "Absolute Measurements in Electricity and Magnetism."

A reflecting magnetometer, M, of the well-known form devised by Mr. J. T. Bottomley, was used to measure the intensity of magnetisation. In the experiments on the wires it was placed due magnetic east of the coil, at a distance of 1 metre from the middle point of its axis, and in such a position that if the axis were produced it would pass through the centre of the mirror. In the experiments on the bars its position was due magnetic north of the coil.

A framework, holding a lamp L, and having a scale S of half-millimetre divisions attached to it, was placed in front of the magnetometer at such a distance that the scale was exactly 1 metre from the magnetometer needle. The light from the lamp, passing through a tube T in front, in which a fine wire is vertically fixed, is reflected from the mirror to the scale, and the deflection read by the image of the fine wire in the middle of the spot of light.

The results in these experiments were got by beginning with a feeble magnetising current, which was increased step by step until the maximum obtainable was reached. It was then gradually diminished to zero, when the direction of the current was reversed, and the same process of increasing and diminishing repeated.

The magnetometer readings taken while the current is flowing represent the effect upon the magnetometer needle of the joint electromagnetic action of the current passing through the coil, and the magnetisation it produces in the wire or bar. Hence the effect due to the magnetisation of the wire or bar alone is obtained by subtracting from the total effect the magnetic effect of the coil. This last is proportional to the current flowing, and was found by experiment to be for the "wire" coil 0·0385, and for the "bar" coil 0·0326 of a division of the magnetometer scale per division of the galvanometer scale.

The results of the investigation are shown in the accompanying curves. The abscissæ are divisions of the galvanometer scale, and are therefore proportional to the magnetising forces. The ordinates are divisions of the magnetometer scale, and are therefore proportional to the magnetisation produced. The curves marked A represent the

total, and those marked B the residual magnetisation. Beginning at zero, we pass to the right, gradually increasing the magnetising force until we reach our limit. Then returning, we pass through zero, and with the opposite magnetising force proceed to the left limit, from which we again return to zero.

The first experiments were made upon the wires, the results of which are given in Curves I, II, III, and IV. These wires were afterwards annealed and retested, with the results shown in Curves V to VIII inclusive. The remaining Curves IX, X, and XI, contain the results obtained from the bars.

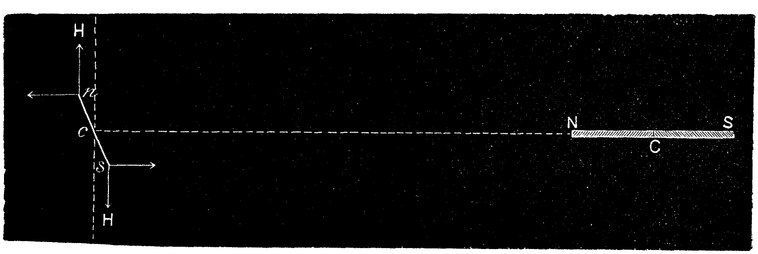
The results given by the curves may be reduced to absolute measure by means of the figures on each, which were obtained in the following manner:—

Let—

$H =$ the horizontal component of the earth's magnetic force.
$M =$ the magnetic moment of the wire or bar.
$m =$ the magnetic moment of the magnetometer needle.
$F =$ the strength of a pole of the wire or bar.
$f =$ the strength of a pole of the needle.
$r =$ the distance of the centre of the wire or bar from that of the needle.
$a =$ half the distance between the poles of the wire or bar.
$b =$ half the distance between the poles of the magnetometer needle.
$\theta =$ the angle of deflection of the magnetometer needle.

The position of the wire, with regard to the magnetometer in the experiments on the wires, is shown in fig. 2.

Fig. 2.



The pole N of the wire attracts the pole s of the needle with a force $\frac{Ff}{(r-a)^2}$, and the pole S repels the pole s with a force $\frac{Ff}{(r+a)^2}$, b being so small in comparison with r that the poles of the

needle may be regarded as at its centre c. Hence the total attractive force exerted on the pole s is—

$$Ff\left\{\frac{1}{(r-a)^2}-\frac{1}{(r+a)^2}\right\}, \text{ or } Ff\frac{4ar}{(r^2-a^2)^2}, \text{ that is } f\frac{2Mr}{(r^2-a^2)^2}.$$

We find similarly that the pole N exerts an equal repulsive force on the pole n. The needle is therefore acted on by a "couple"—

$$2bf\frac{2Mr}{(r^2-a^2)^2}\cos\theta, \text{ that is } \frac{2Mmr}{(r^2-a^2)^2}\cos\theta.$$

To balance this we have another "couple," $f\text{H}.2b\sin\theta$, that is, $m\text{H}\sin\theta$. Hence, equating these two couples, we get—

$$\text{M}=\frac{(r^2-a^2)^2}{2r}\text{H}\tan\theta. \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

The value of H at this point was found to be 0·16, by comparison with a particular spot in the laboratory, for which, by the method fully described in Mr. Thomas Gray's paper on "The Experimental Determination of Magnetic Moments in Absolute Measure" ("Philosophical Magazine," November, 1878), the value of H had already been very accurately determined. Half the distance between the poles of the wire, represented by a, may be taken as half its length, that is, 15·5 cm. The angle through which the magnetometer needle is deflected is measured on the half-millimetre scale; and for small angles $\tan\theta = \frac{1}{2}\tan 2\theta$; so $\tan\theta$ is got by dividing the scale reading by $2r$ in half-millimetres, that is by 4000. By substituting these values in equation (1), we find that the magnetic moments are obtained by multiplying the readings of the magnetometer scale, which in the curves are represented by the ordinates, by the factor 19·110125. The magnetic moments *per gram* are therefore got by multiplying the ordinates in—

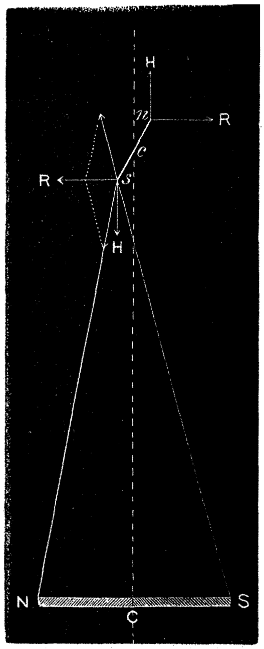
Curves	I	and	V	by	0·4795.
„	II	„	VI	„	0·479.
„	III	„	VII	„	0·4605.
„	IV	„	VIII	„	0·4964.

The position of the bar with regard to the magnetometer in the experiments on the bars, is shown on fig. 3.

The pole N of the bar attracts the pole s of the needle with a force $\frac{Ff}{r^2+a^2}$, and the pole S repels the pole s with an equal force. The

resultant of these two forces is a force R, parallel to the bar, and of value $2\mathrm{F}f\frac{a}{(r^2+a^2)^{\frac{3}{2}}}$,* that is $f\frac{\mathrm{M}}{(r^2+a^2)^{\frac{3}{2}}}$.

Fig. 3.



A force, equal and parallel to this, but in the opposite direction, may be similarly shown to act on the pole n of the needle. Thus the needle is acted on by a "couple," the value of which is—

$$2bf\frac{\mathrm{M}}{(r^2+a^2)^{\frac{3}{2}}}\cos\theta,\text{ that is }\frac{\mathrm{M}m}{(r^2+a^2)^{\frac{3}{2}}}\cos\theta.$$

To balance this "couple" we have, as before, another "couple," $m\mathrm{H}\sin\theta$. Hence, equating these, we get—

$$\mathrm{M}=(r^2+a^2)^{\frac{3}{2}}\mathrm{H}\tan\theta. \quad \ldots\ldots \quad (2.)$$

Now, in these experiments, r is 100 cm., a 7·6 cm., and H was found to be 0·155. Substituting these values in equation (2), we

* $\mathrm{R}^2=2\left(\frac{\mathrm{F}f}{r^2+a^2}\right)^2(1-\cos \mathrm{S}s\mathrm{N})$; but $\cos \mathrm{S}s\mathrm{N}=\cos^2\frac{1}{2}\mathrm{S}s\mathrm{N}-\sin^2\frac{1}{2}\mathrm{S}s\mathrm{N}=\frac{r^2-a^2}{r^2+a^2}$; hence $\mathrm{R}=2\frac{\mathrm{F}f}{r^2+a^2}\cdot\frac{a}{\sqrt{r^2+a^2}}=f\frac{\mathrm{M}}{(r^2+a^2)^{\frac{3}{2}}}$.

find that the magnetic moments of the bars are got by multiplying the ordinates by 41·085378. Therefore, to get their magnetic moments *per gram*, we have to multiply the ordinates of IX and X by 0·3604, and those of XI by 0·3287.

The magnetising force is evaluated by the equation—

$$F=4\pi nC. \qquad (3.)$$

where n is the number of turns of wire in the coil per centimetre of its length, and C the current strength in c.g.s. units passing through it.

The abscissæ of the curves are scale divisions of the galvanometer, with its magnetometer at the platform division 32, or the readings at other divisions reduced to those of this division. Thus the abscissæ multiplied by $\frac{H}{10\times 32}$ represent the currents in absolute measure. The magnetising force F is therefore obtained from the curves by multiplying the abscissæ by $4\pi n\frac{H}{320}$, or $\pi n\frac{H}{80}$. In the first eight experiments, $n=45$, and $H=0{\cdot}16$; thus we have 0·2828 as the factor for reducing the abscissæ of the curves I to VIII inclusive. The abscissæ of curves IX, X, and XI are reduced by the factor 0·224, n being 37, and H 0·16.

From a comparison of the curves Nos. I to IV inclusive, it will be seen that the "charcoal iron" has the highest magnetisability, and the "soft steel" the lowest, while that of the "soft Scotch iron" approaches very near to the former. With regard to retentiveness, the "charcoal iron" shows the least, and the "soft steel" the greatest.

Passing on to curves V to VIII inclusive, we find that the general effect of annealing the wires has been to lower their retentiveness, and to raise their magnetisability for all forces. In the "soft Scotch iron" wire little difference has been made; but in the others the effect is very marked, and is most noticeable in the "charcoal iron" wire with respect to its magnetisability, and in the case of the "soft steel" wire with respect to its retentiveness. Comparing the results of these eight experiments then, we find that the specimen which has the highest magnetisability, and at the same time the lowest retentiveness, is the annealed "charcoal iron" (7). Coming next to this specimen, in both respects we have the "charcoal iron" wire (3), and the annealed "common wire" (6), between which there is little or no difference. The "soft steel" wire is the lowest of all in respect of magnetisability, and highest in retentiveness. Annealing it, however (8), has had the effect of bringing it very close to the "common wire" (2).

As regards the bars, the second specimen of cast iron is greatly

inferior to the first in respect of magnetisability. The malleable iron bar exhibits a very much higher magnetisability than the cast iron bars; and its residual magnetisation was so low that it could not be observed with the same arrangement of apparatus.

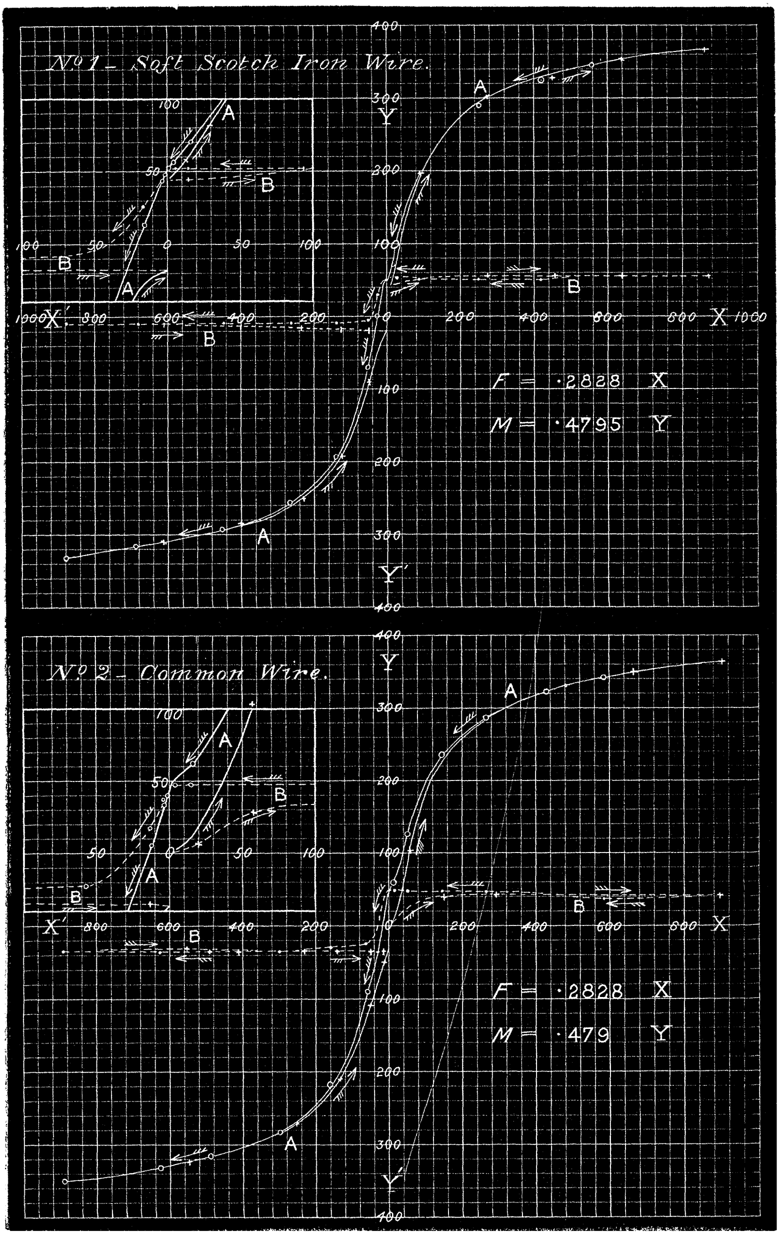
These are the main points in a comparison of the results of the experiments. A study of the curves, however, reveals many points of interest, one or two of which I may here indicate.

The curve beginning from the zero of magnetisation was not obtained in all the experiments, the wires having been previously magnetised in a preliminary test; but in those cases in which the smallest magnetising forces were employed, the curve of results is seen to be for a short distance concave towards OY.

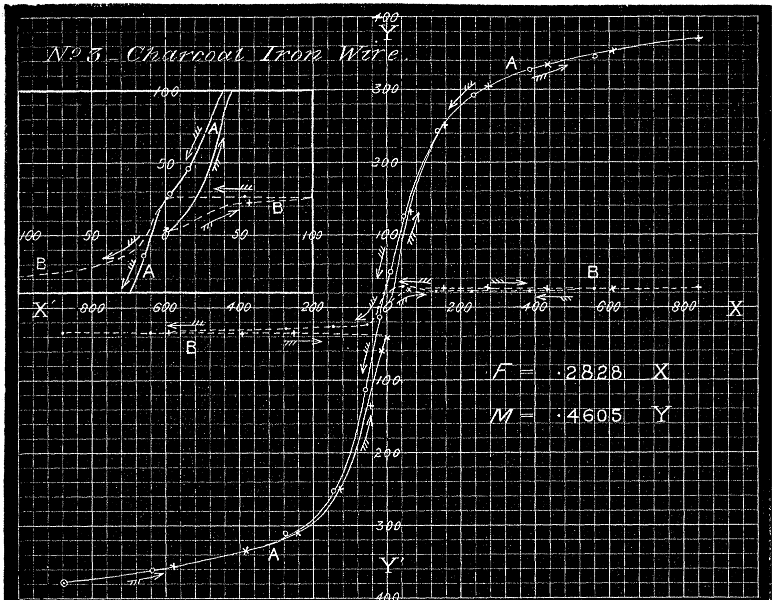
Returning again to the small magnetising forces after having proceeded to the limit, we find the curve first becoming concave towards OY, and then convex just before it crosses that line. On the negative side of OY, it remains concave for but a short distance, and is convex when it crosses the line of zero magnetisation, remaining so both in the direct and the return curves until we again near the zero of magnetising force, when it becomes concave for a short distance up to zero. To show these points clearly, the central portion on an enlarged scale has been affixed to each set of curves.

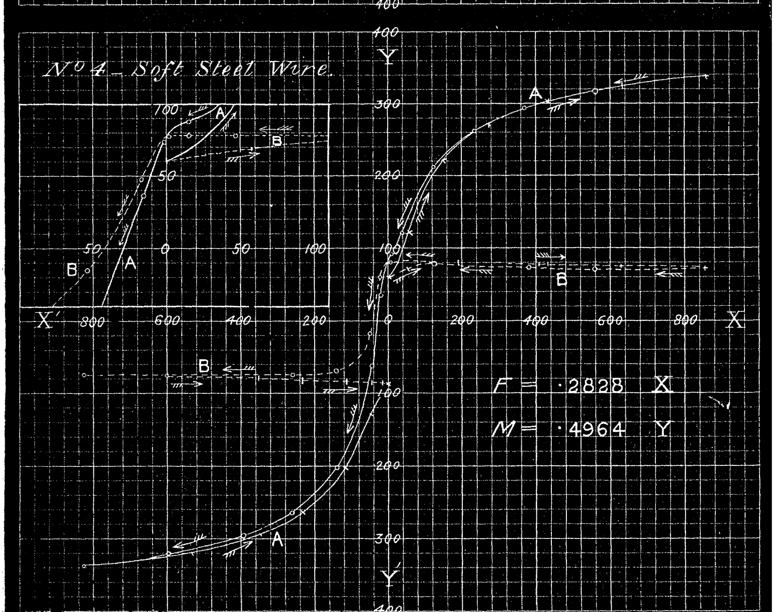
Turning to the curves for the residual magnetisation, an interesting point at once presents itself. This is a loop between the direct and return curves, more or less marked in most of the diagrams, but best seen in No. IV. A similar loop is seen in the curves of total magnetisation in Nos. V and VII, and there seems to be a tendency to form such a loop in all these curves. Regarding that part of the positive return curve which represents the effects of the small magnetising forces, we see that the residual magnetisation first begins to take a greater value, and then diminishes again just before the zero of magnetising force is reached.

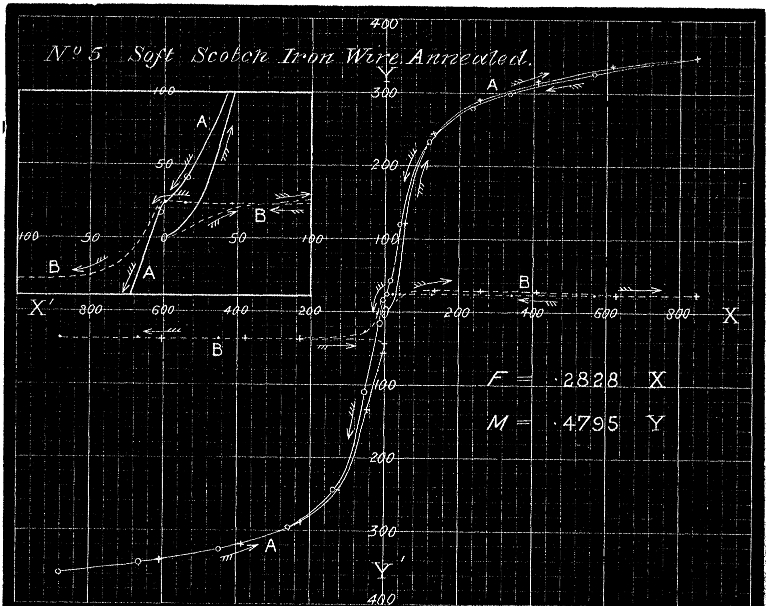
I shall defer any discussion of these anomalies until I have made a further observation of them under conditions more suitable for their special investigation.

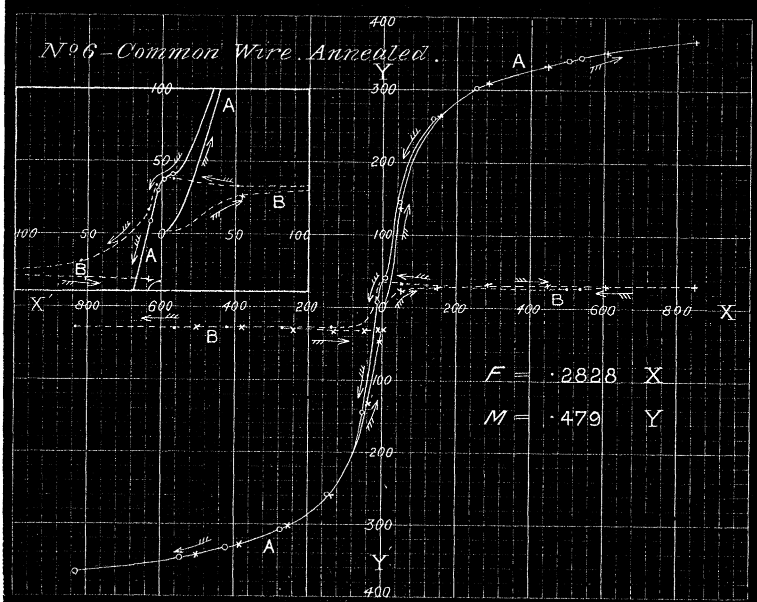


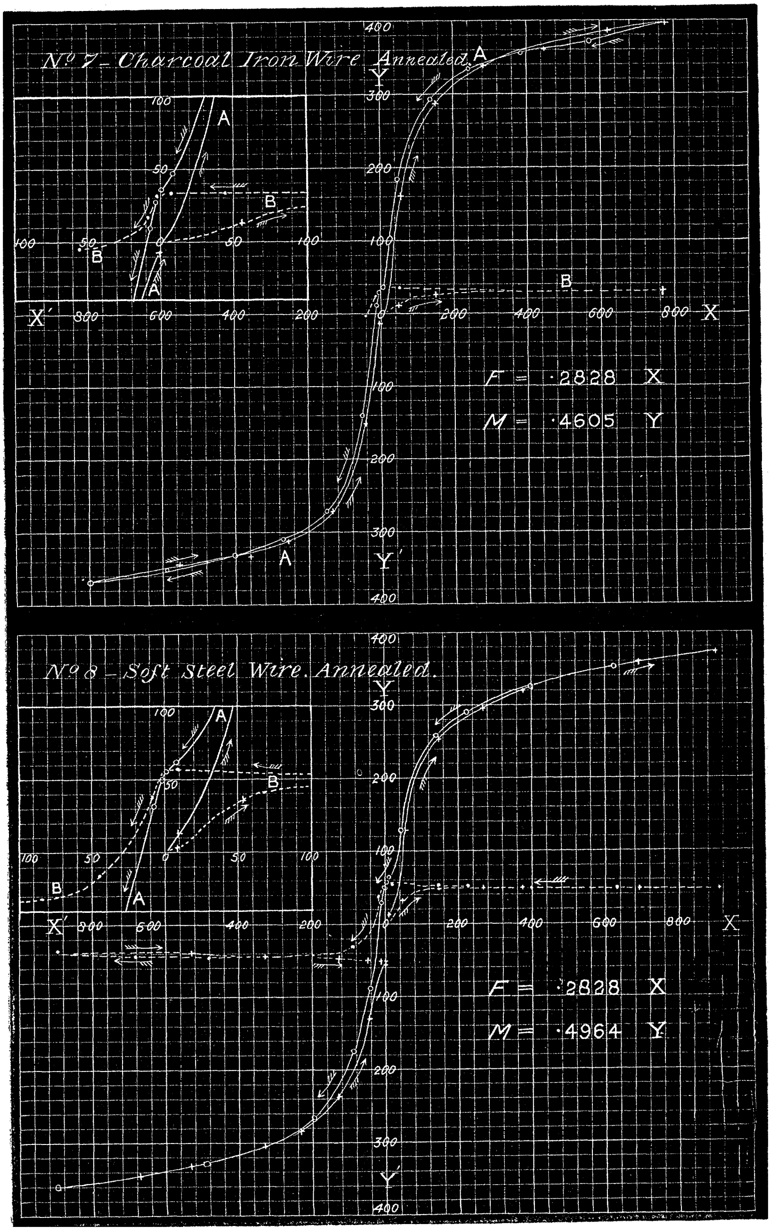
Nº 1 – Soft Scotch Iron Wire.
F = ·2828 X
M = ·4795 Y
Nº 2 – Common Wire.
F = ·2828 X
M = ·479 Y

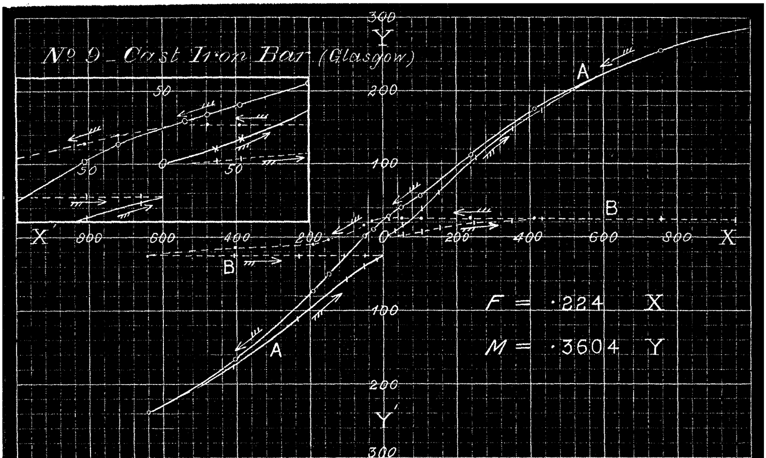

Nº 3 _ Charcoal Iron Wire.
F = ·2828 X
M = ·4605 Y
A
B
X
X′
Y
Y′

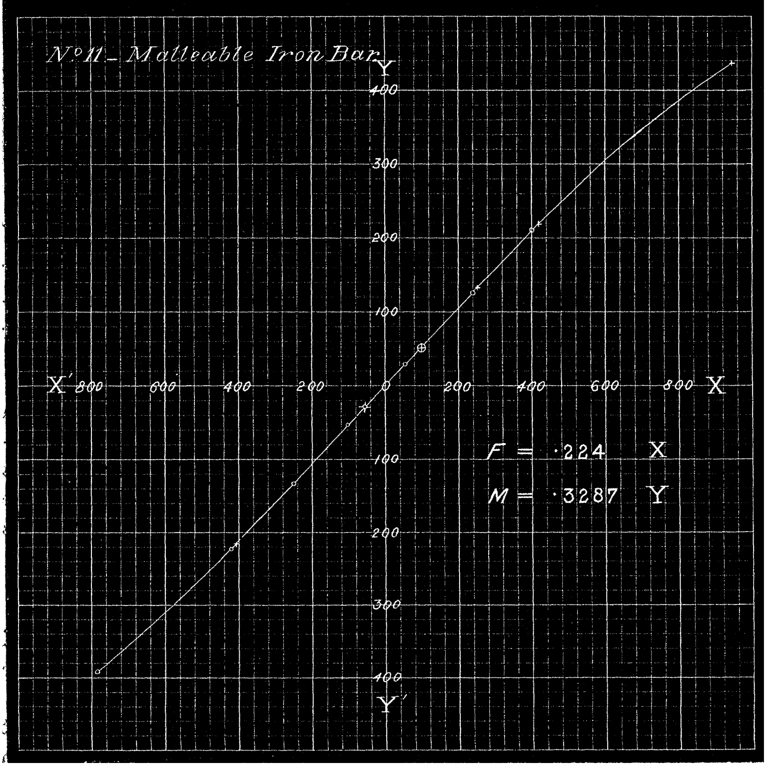

Nº 4 _ Soft Steel Wire.
F = ·2828 X
M = ·4964 Y
A
B
X
X′
Y
Y′

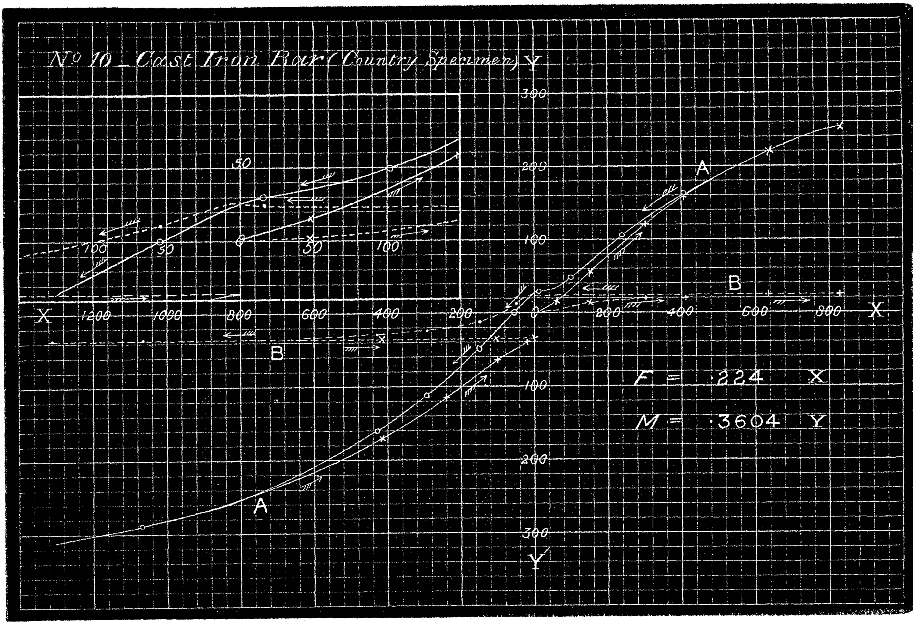

No. 5 Soft Scotch Iron Wire Annealed.
F = ·2828 X
M = ·4795 Y
X′
X
Y
Y′
A
B


No. 6 – Common Wire Annealed.
F = ·2828 X
M = ·479 Y
X′
X
Y
Y′
A
B


Nº 7 – Charcoal Iron Wire Annealed.
F = ·2828 X
M = ·4605 Y
Nº 8 – Soft Steel Wire Annealed.
F = ·2828 X
M = ·4964 Y


Nº 9_Cast Iron Bar (Glasgow)
F = ·224 X
M = ·3604 Y
A
B
X′
X
Y
Y′
800
600
400
200
0
200
400
600
800
300
200
100
100
200
300
50
50
50


Nº 11_Malleable Iron Bar
F = ·224 X
M = ·3287 Y
X′
X
Y
Y′
800
600
400
200
0
200
400
600
800
400
300
200
100
100
200
300
400



III. "On the Limited Hydration of Ammonium Carbamate." By H. J. H. FENTON, M.A., F.C.S., F.I.C., Demonstrator in Chemistry in the University of Cambridge. Communicated by Dr. HUGO MÜLLER, F.R.S. Received November 19, 1885.

It occurred to me that a study of the action of water on ammonium carbamate, with reference to the influence of time, mass, and temperature, would be of interest as tending to throw light upon the laws which govern a chemical action of the simplest type in the liquid state—the action consisting of the direct union of two simpler molecules to form one more complex—

$$CO(NH_2)(ONH_4)+OH_2=CO(ONH_4)_2,$$

There are but few such actions which can be investigated, where all the substances are in the liquid state and all extraneous matter absent.

In a paper read before the Chemical Society in 1879,* I showed that ammonium carbamate when acted upon by sodium hypochlorite in

* "Chem. Soc. Jour.," 35, 12.

FIG. 1.

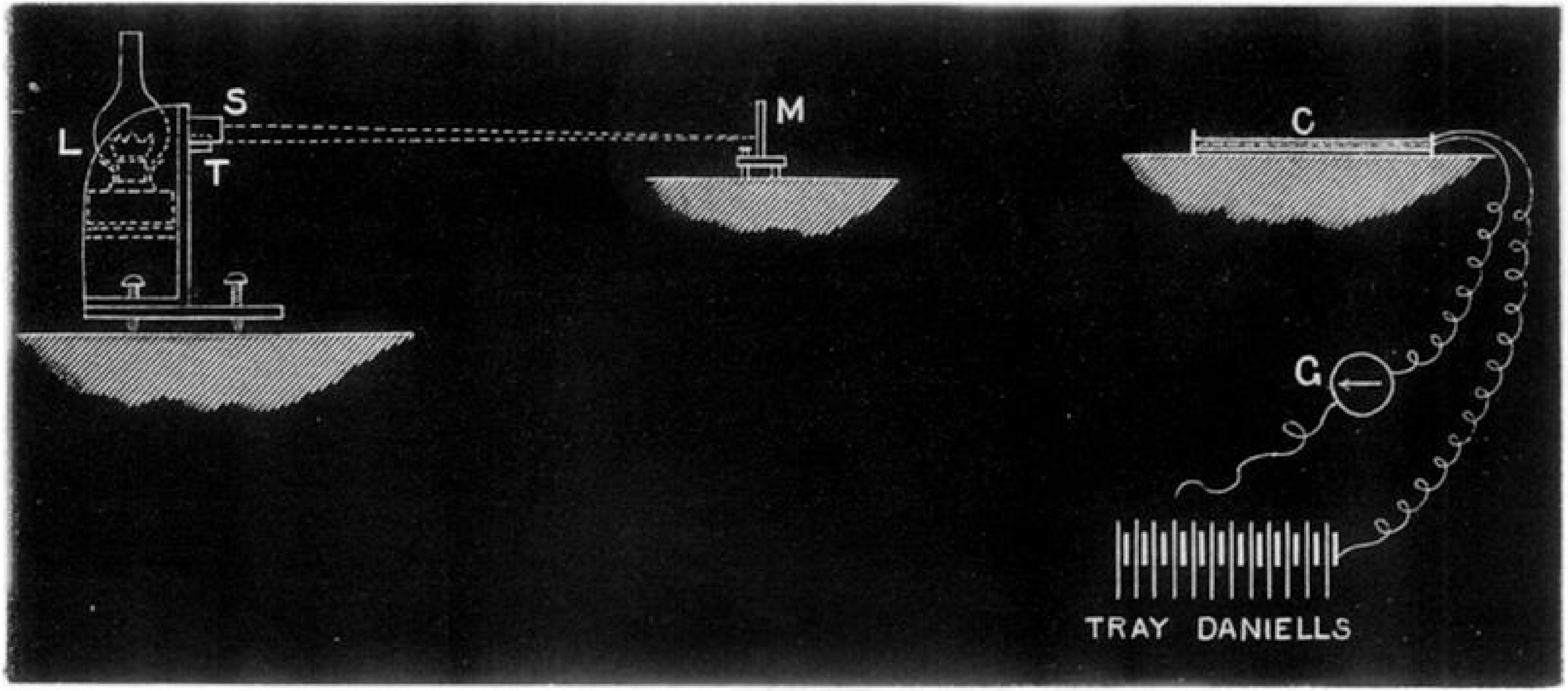


Fig. 2.

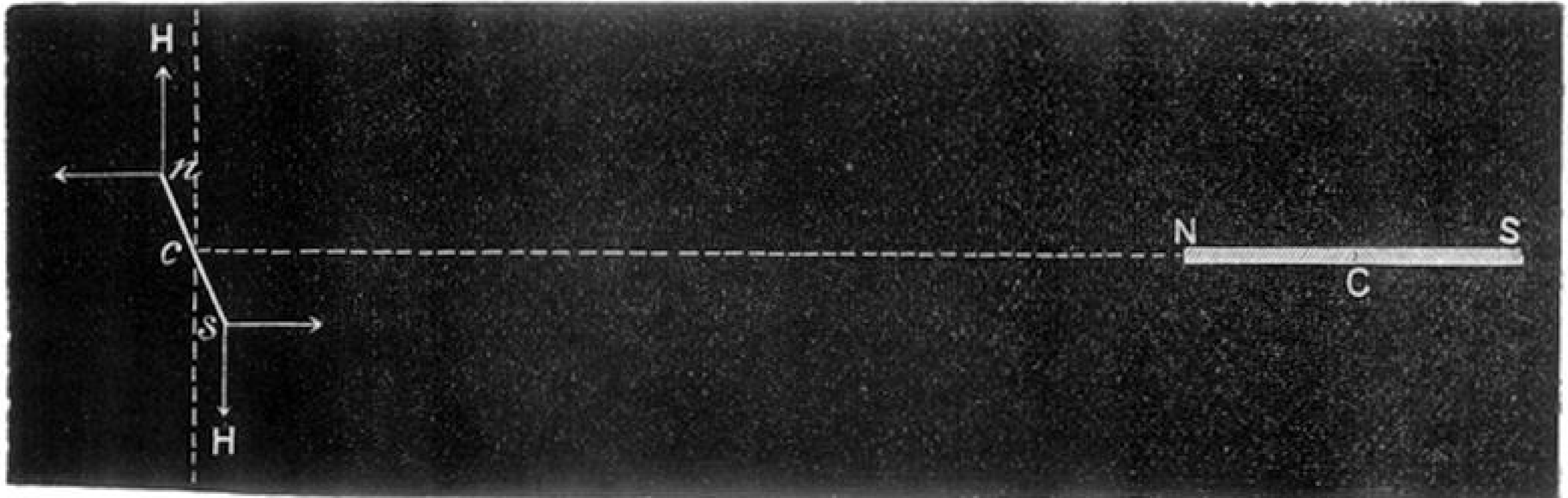
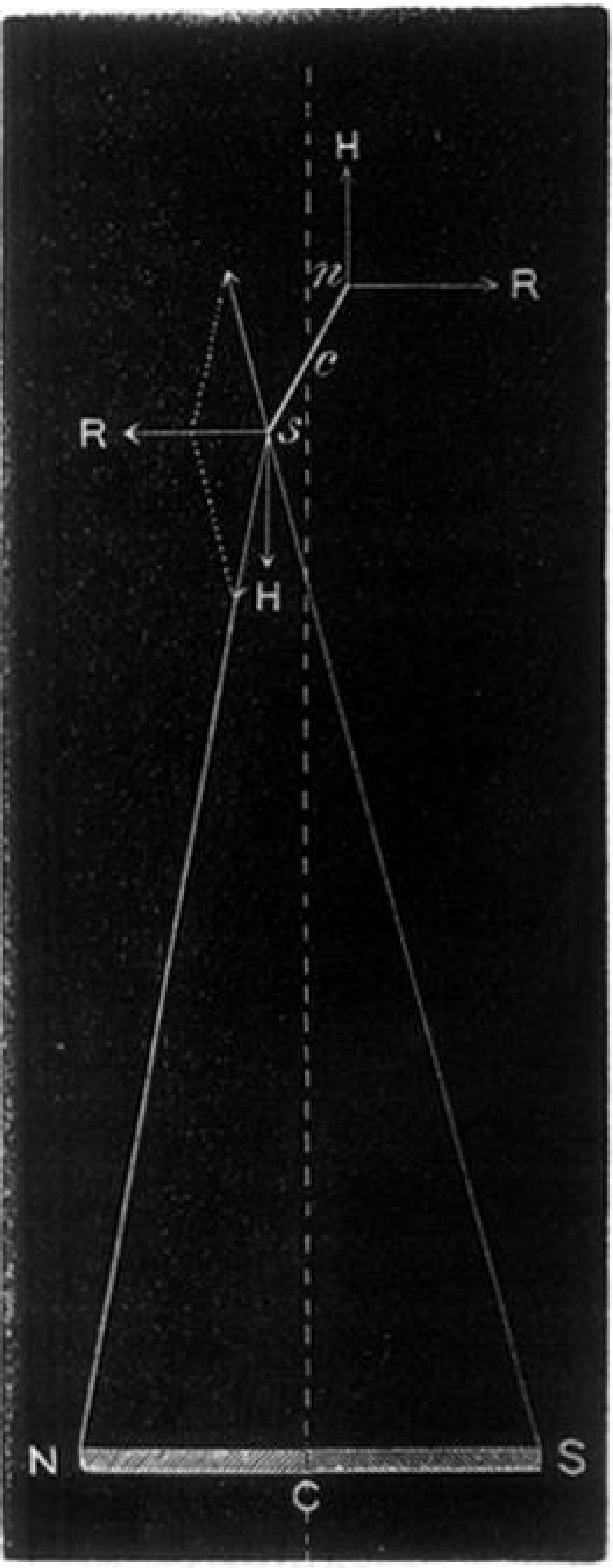
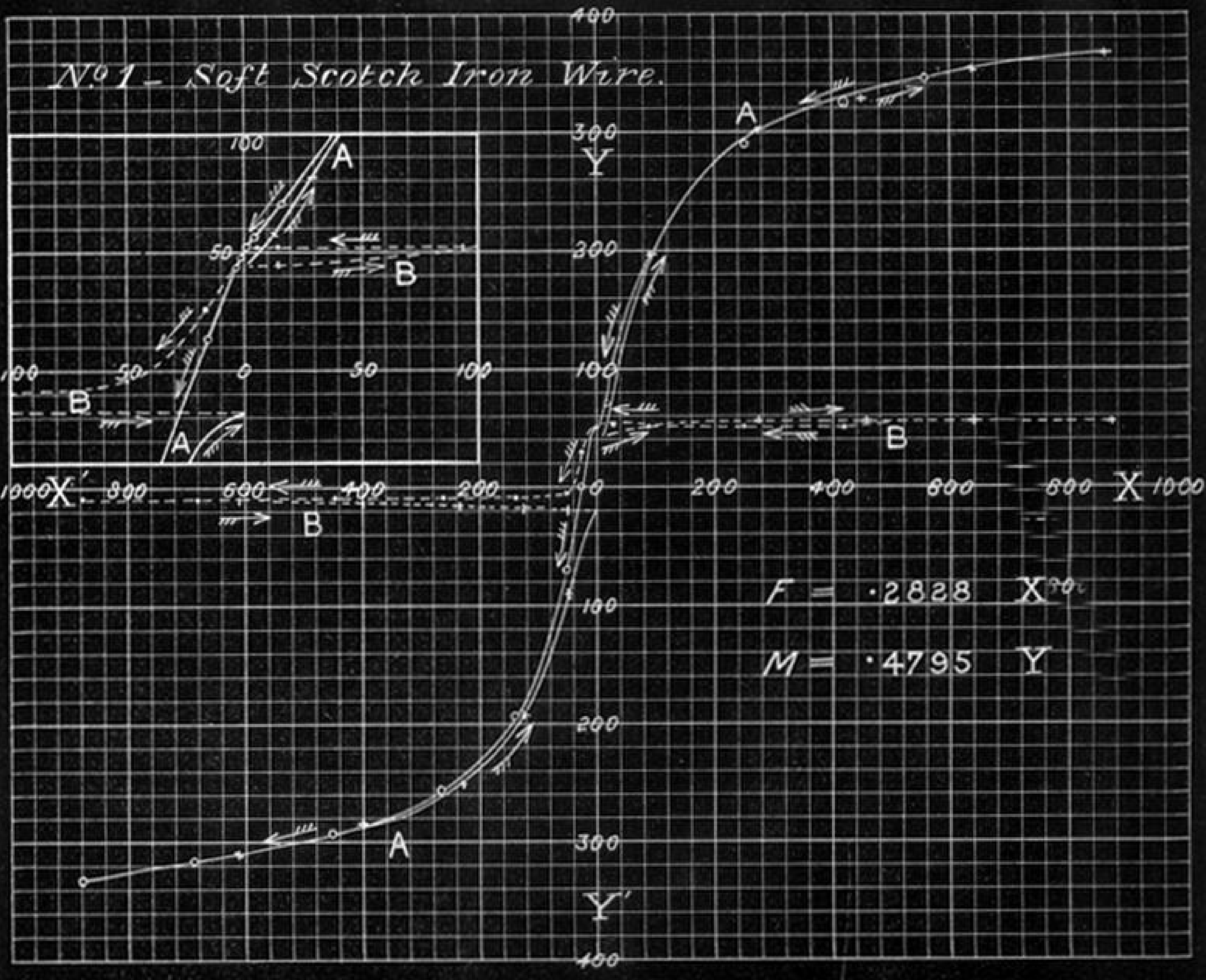
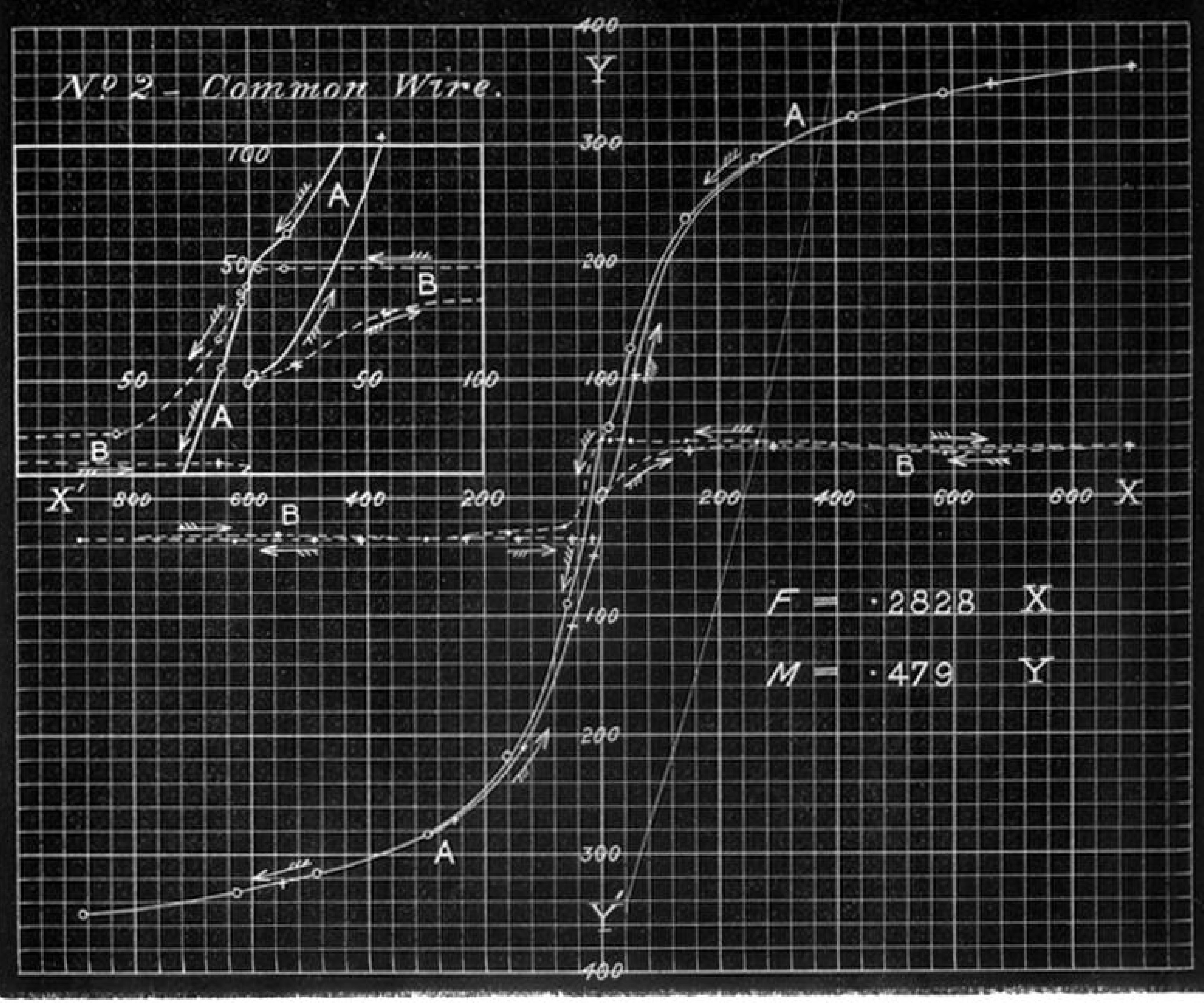


Fig. 3.

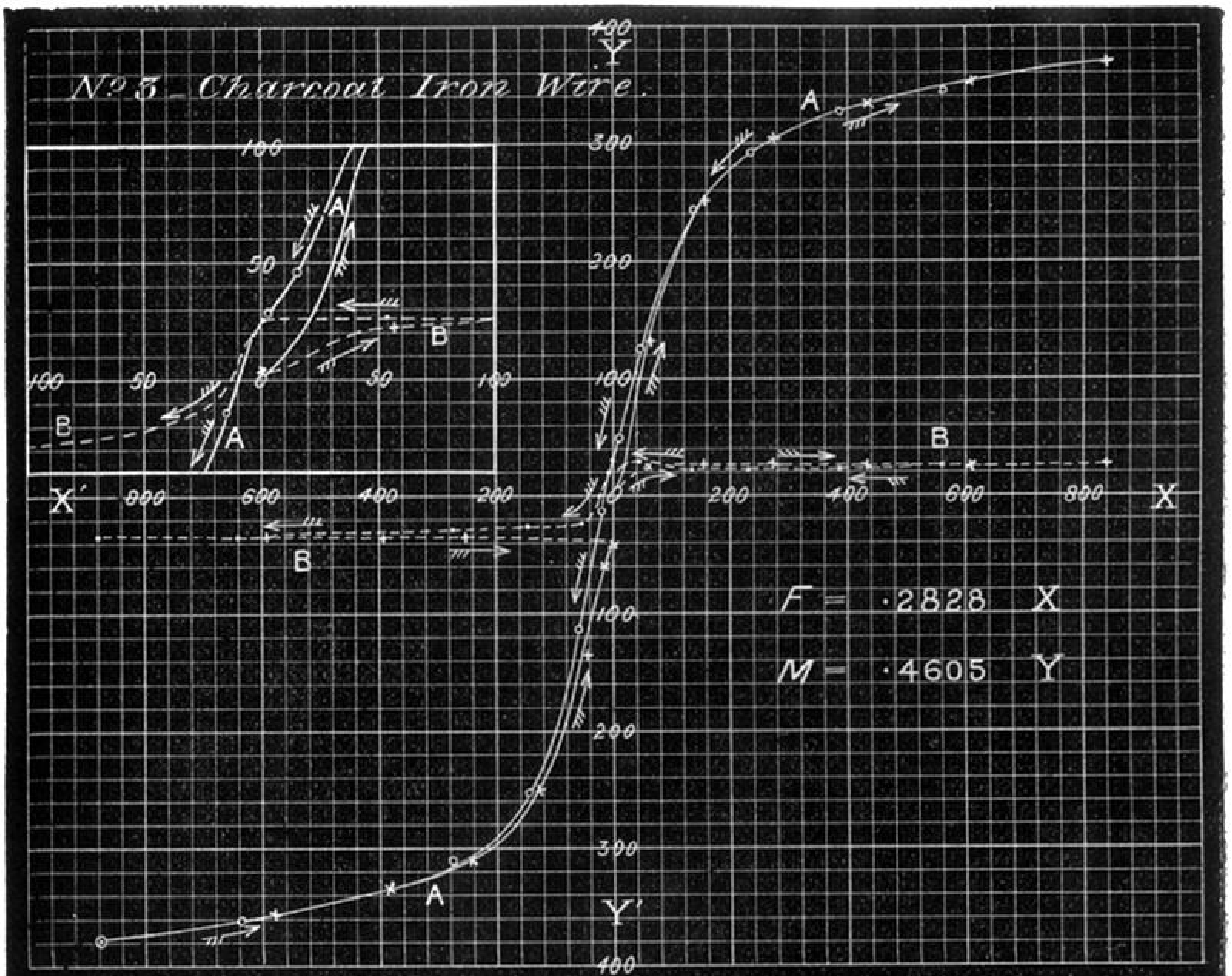


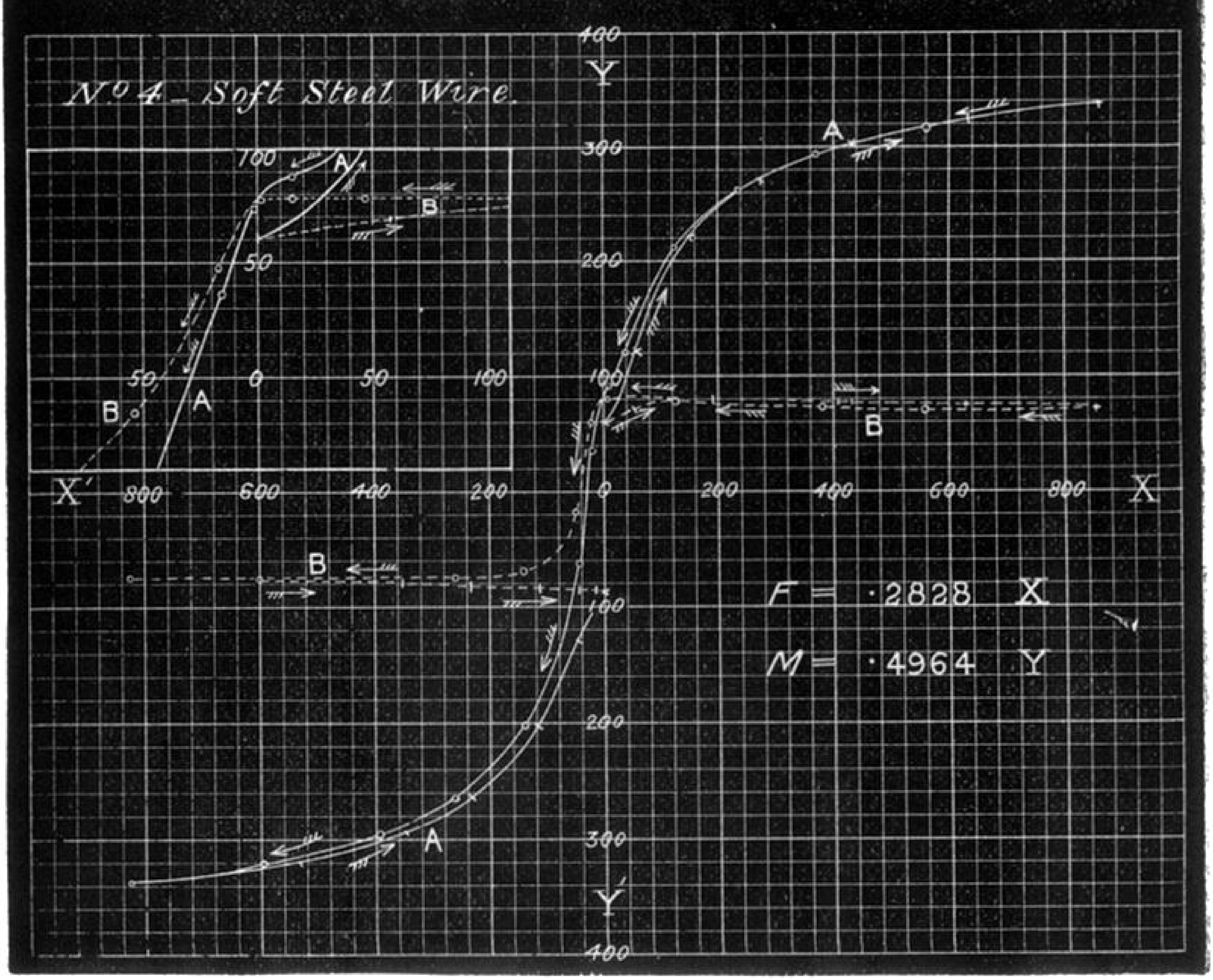


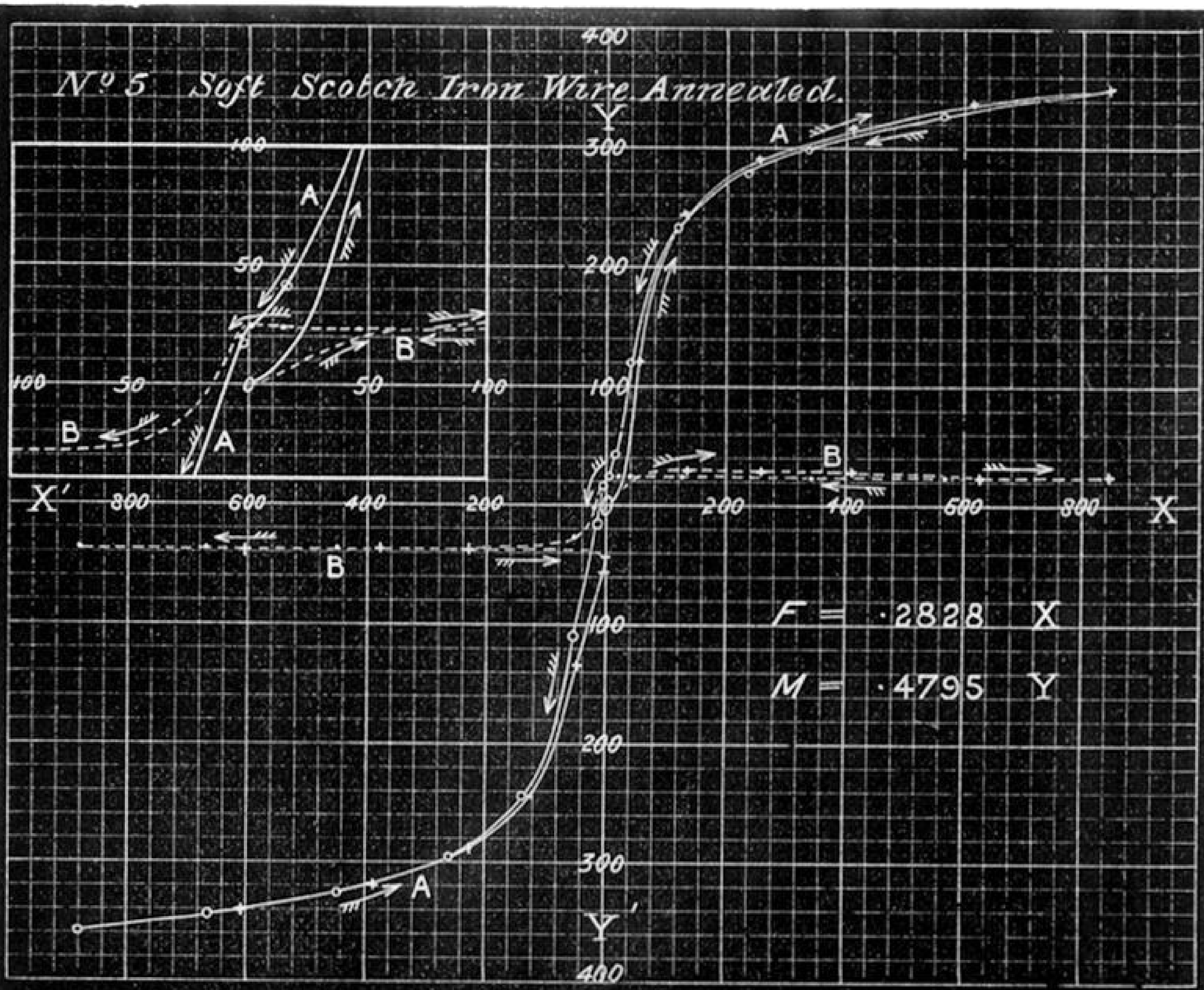
No 1 - Soft Scotch Iron Wire.
Y
Y'
X
X'
A
B
F = ·2828 X
M = ·4795 Y



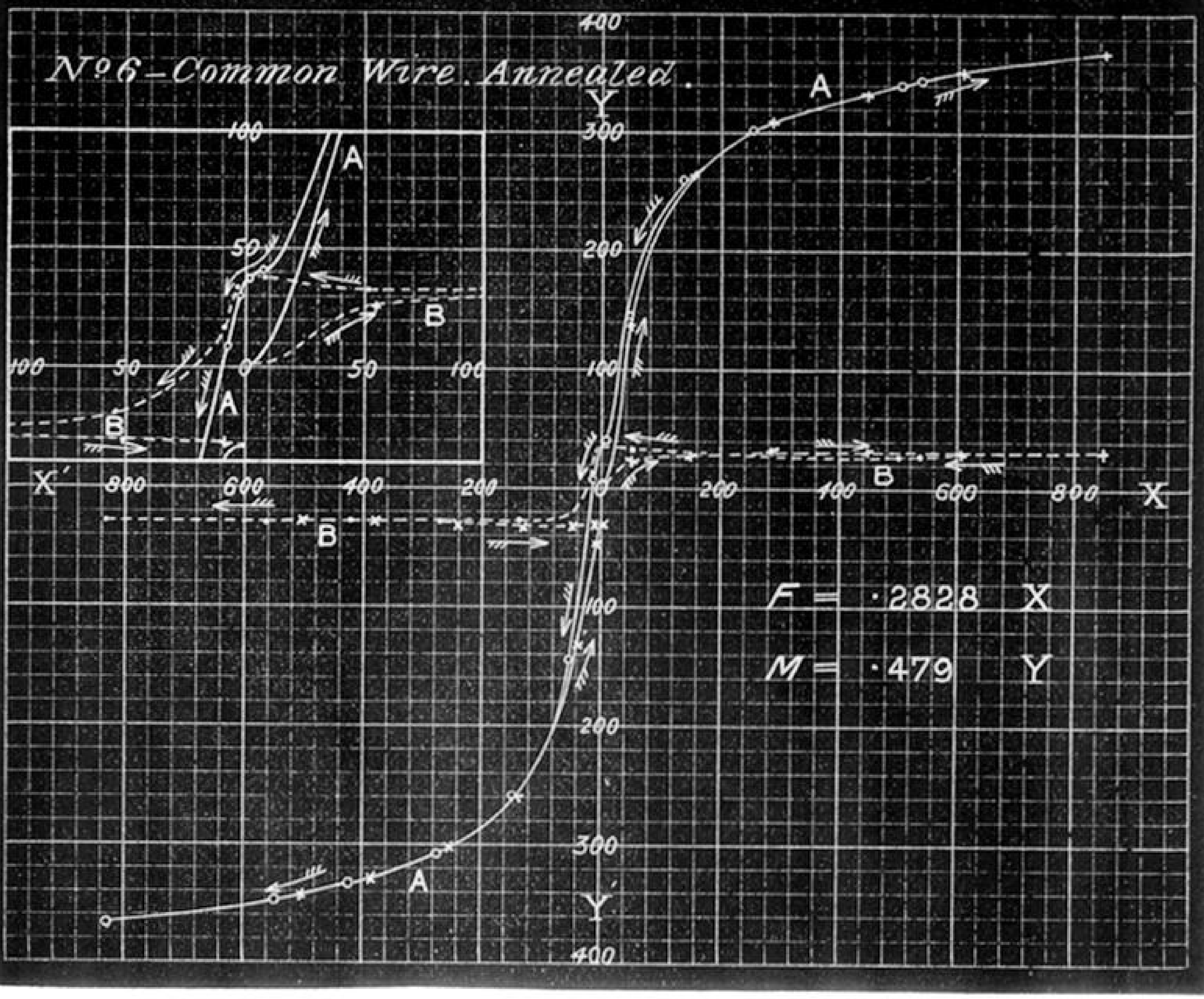
No 2 - Common Wire.
Y
Y'
X
X'
A
B
F = ·2828 X
M = ·479 Y


No. 3 _ Charcoal Iron Wire.
A
B
X
X′
Y
Y′
F = ·2828 X
M = ·4605 Y

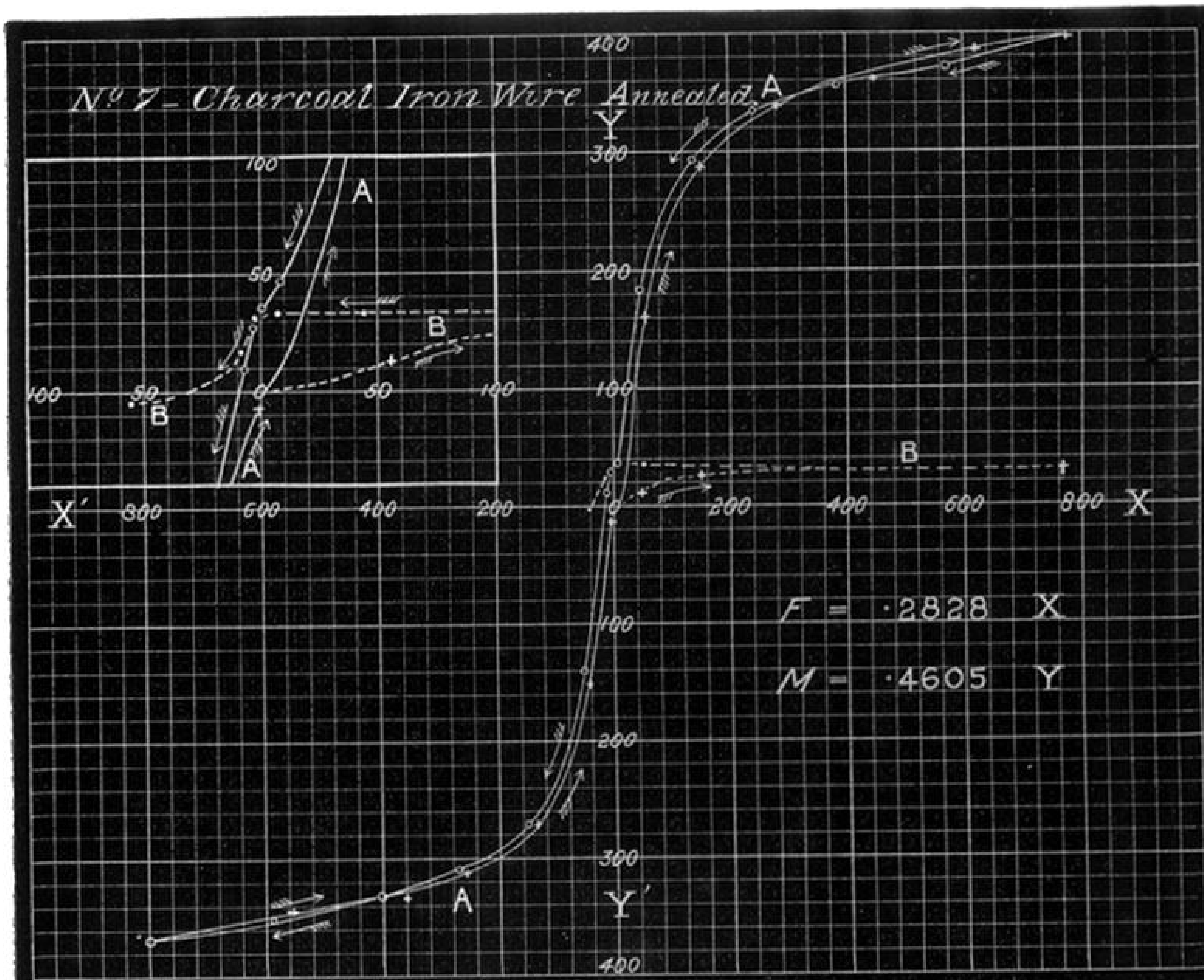

No. 4 _ Soft Steel Wire.
A
B
X
X′
Y
Y′
F = ·2828 X
M = ·4964 Y



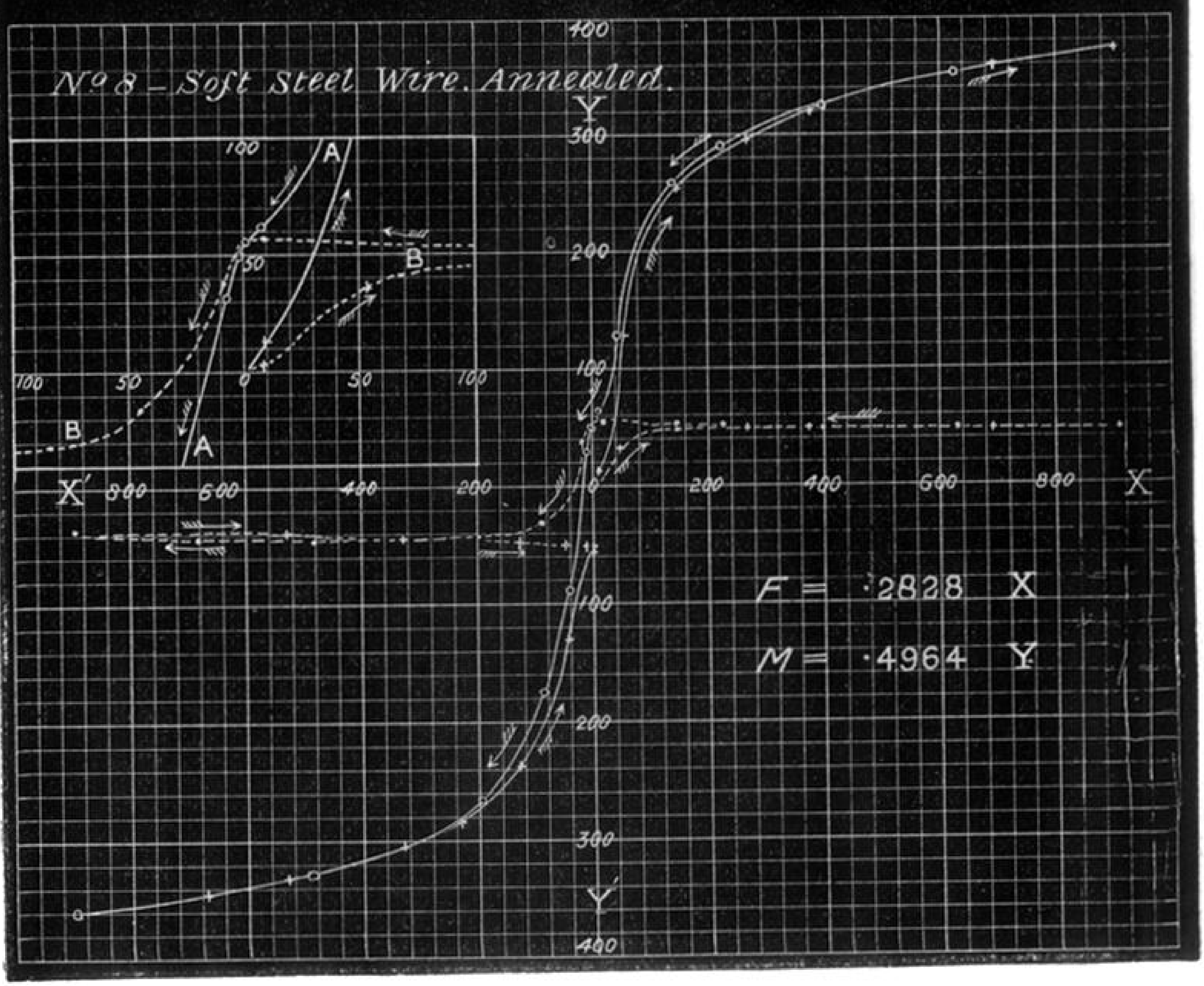
Nº 5 Soft Scotch Iron Wire Annealed.
A
B
X'
X
Y
Y'
F = ·2828 X
M = ·4795 Y



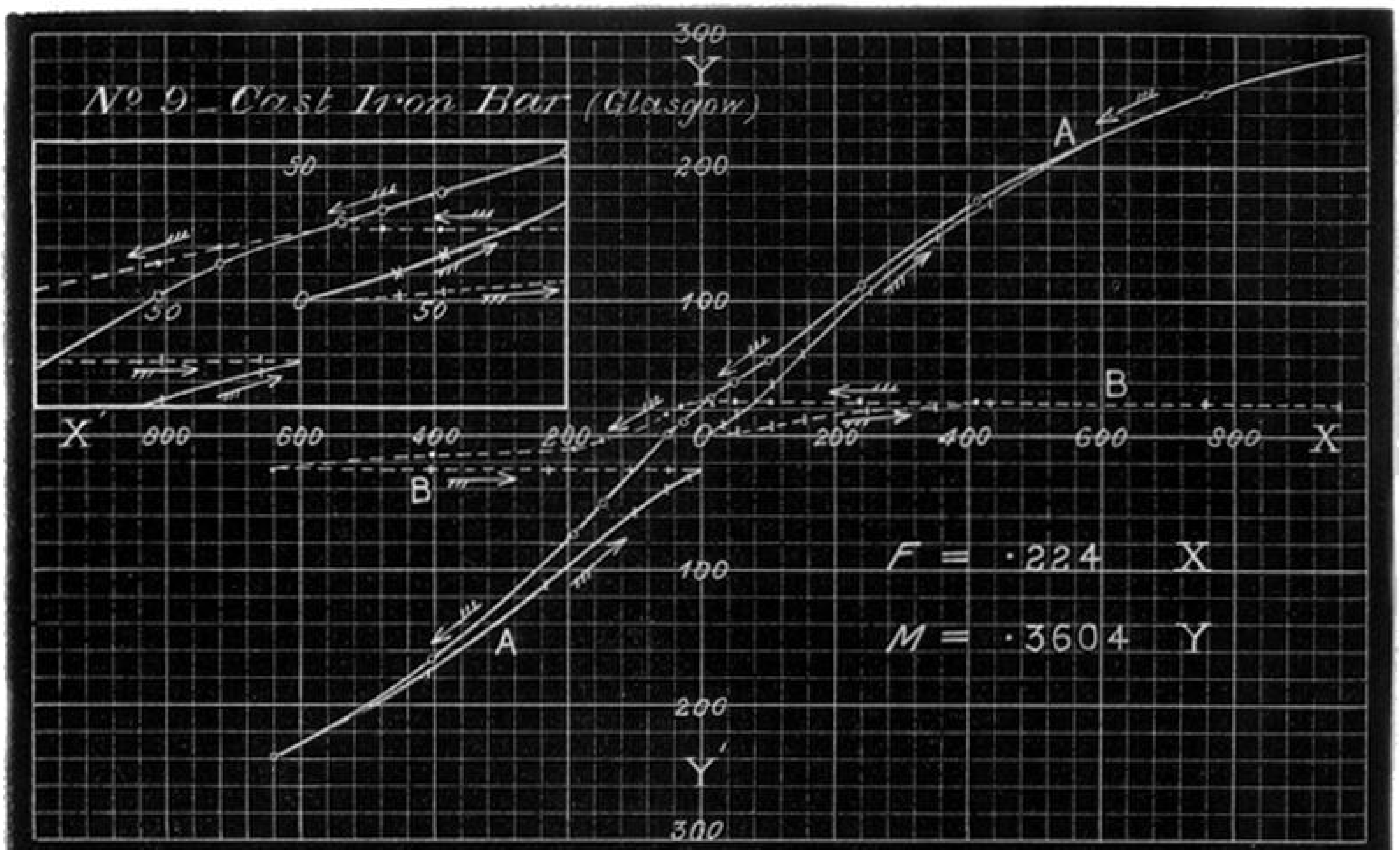
Nº 6 – Common Wire Annealed.
A
B
X'
X
Y
Y'
F = ·2828 X
M = ·479 Y



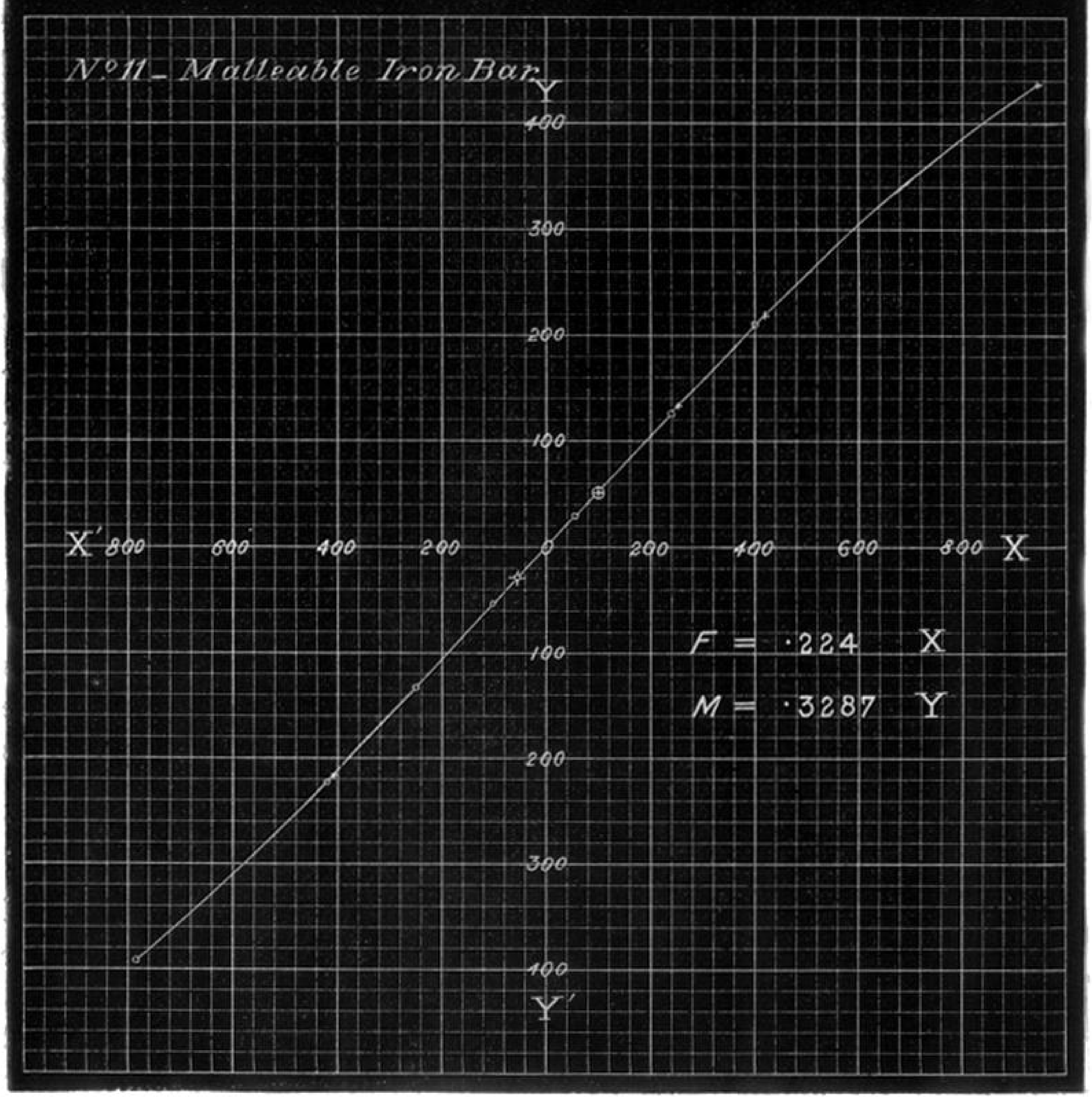
Nº 7 - Charcoal Iron Wire Annealed.
A
B
Y
Y′
X
X′
400
300
200
100
800
600
400
200
100
50
F = ·2828 X
M = ·4605 Y



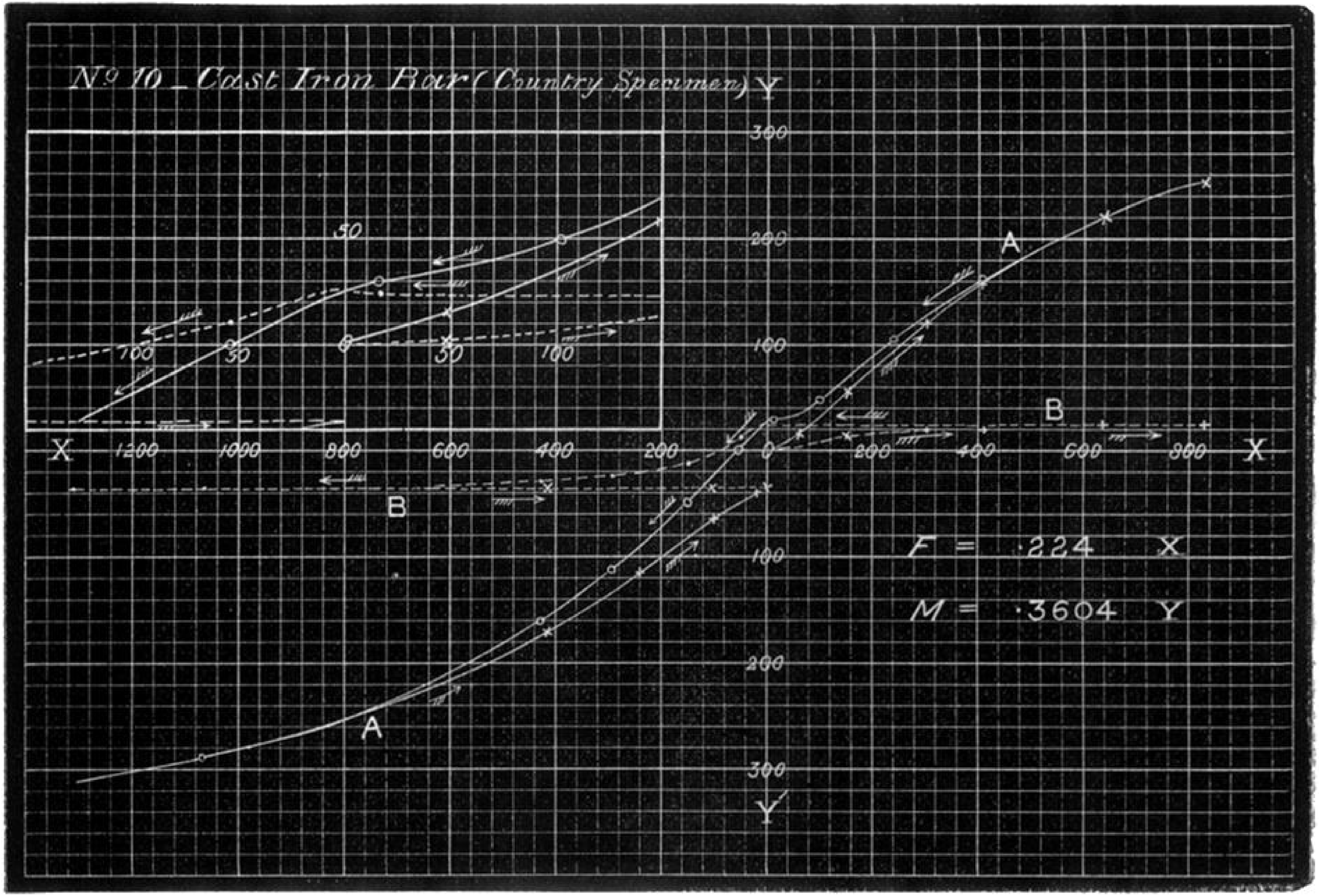
Nº 8 - Soft Steel Wire. Annealed.
A
B
Y
Y′
X
X′
400
300
200
100
800
600
400
200
100
50
F = ·2828 X
M = ·4964 Y



Nº 9 _ Cast Iron Bar (Glasgow)
F = ·224 X
M = ·3604 Y



Nº 11 _ Malleable Iron Bar
F = ·224 X
M = ·3287 Y



No 10 _ Cast Iron Bar (Country Specimen)
Y
300
200
100
0
200
400
600
800
1000
1200
X
A
B
50
700
30
50
100
F = ·224 X
M = ·3604 Y
300
Y'