April 16, 1929. P. P. CIOFFI 1,708,936

MAGNETIC MATERIAL

Filed Dec. 23, 1926 5 Sheets-Sheet 1

Fig. 1.

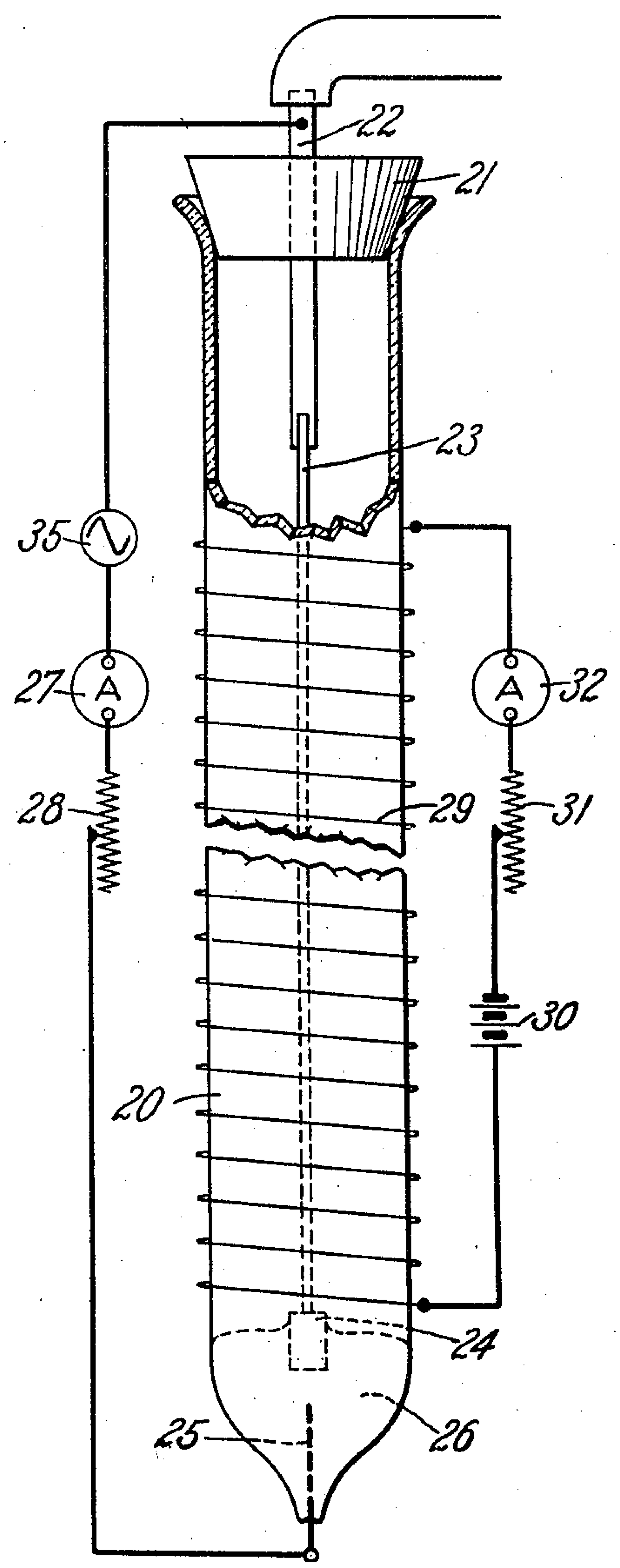

Fig. 2.

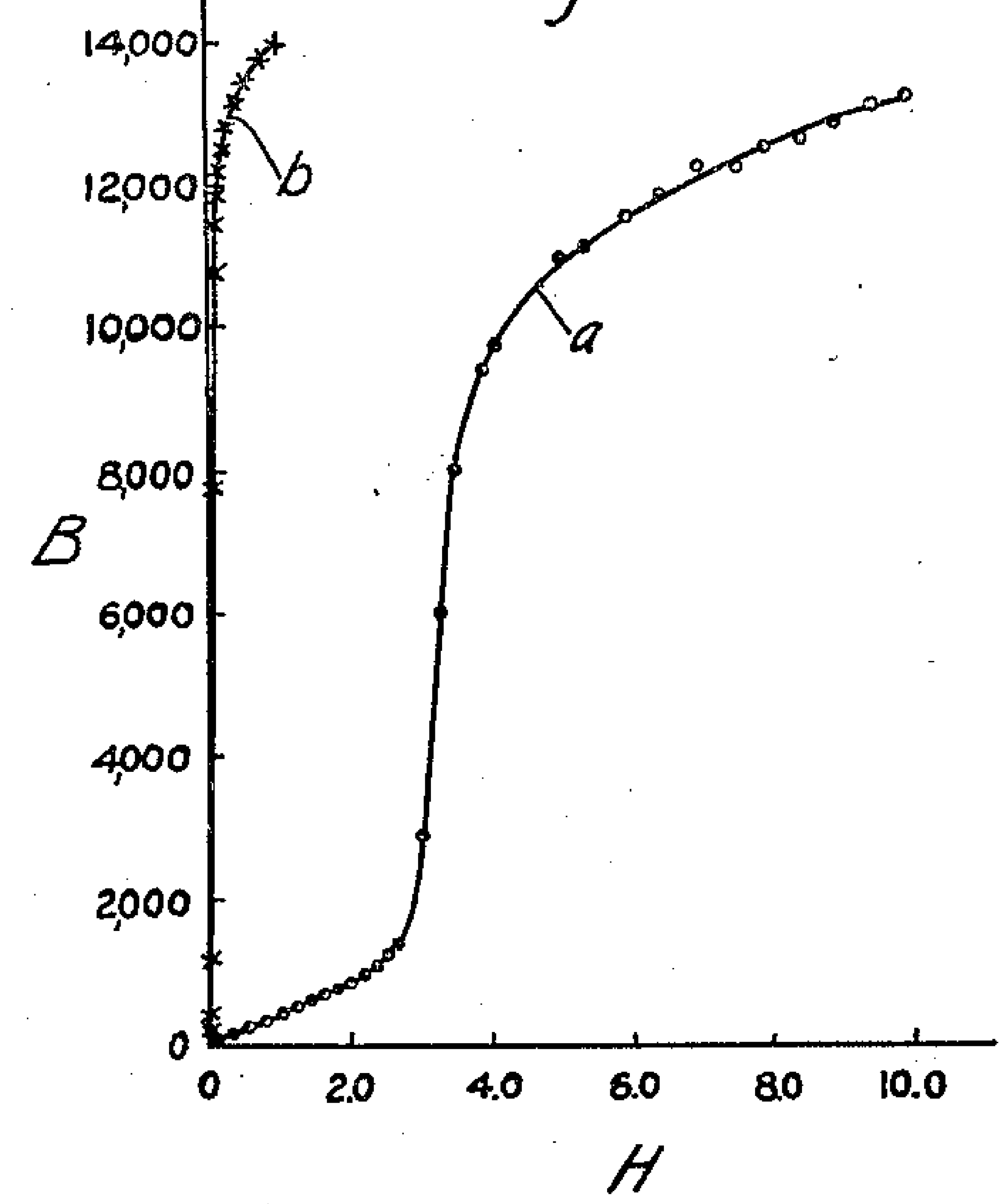

Fig. 3.

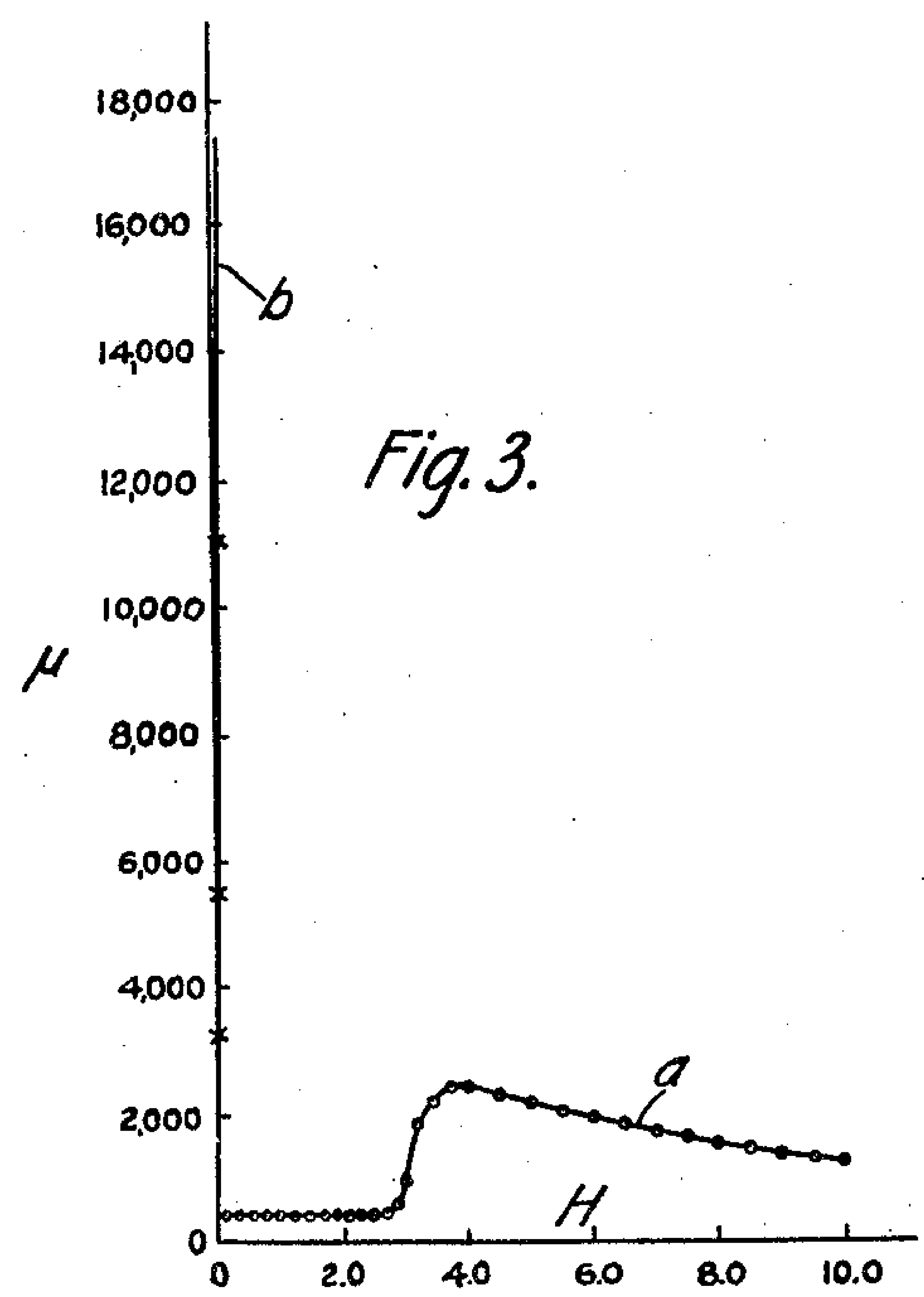

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Fig. 4.

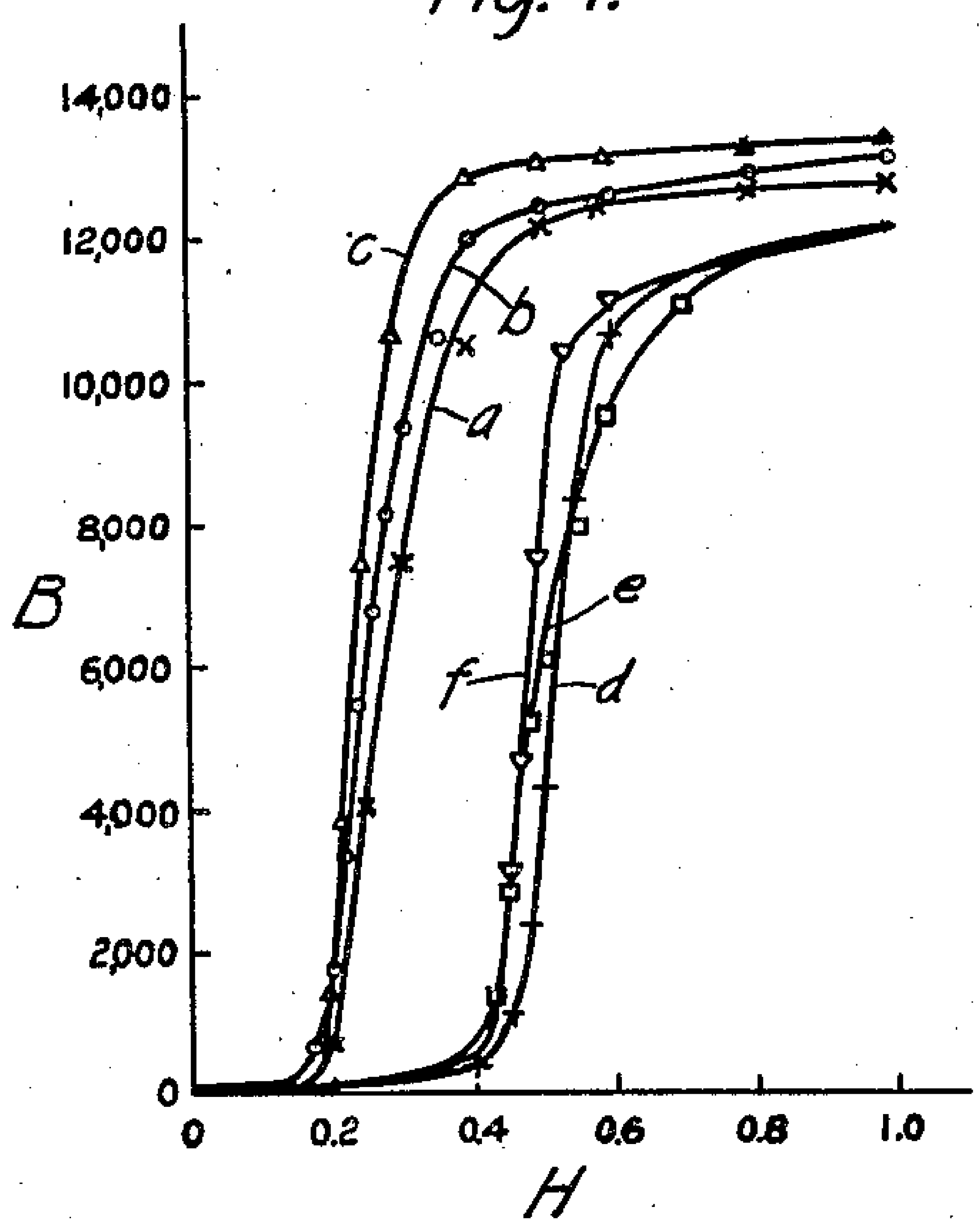


Fig. 5.

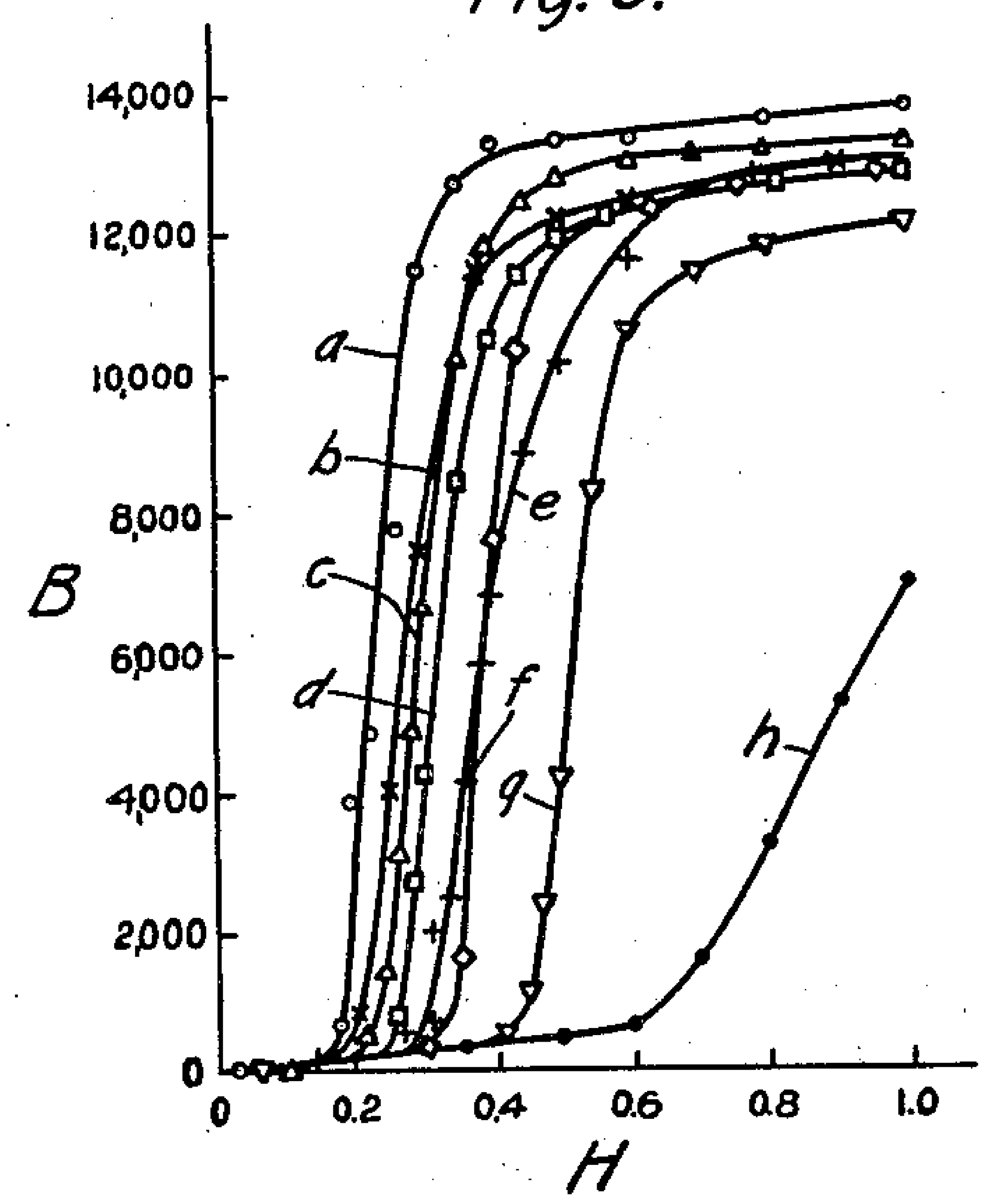


Fig. 6.

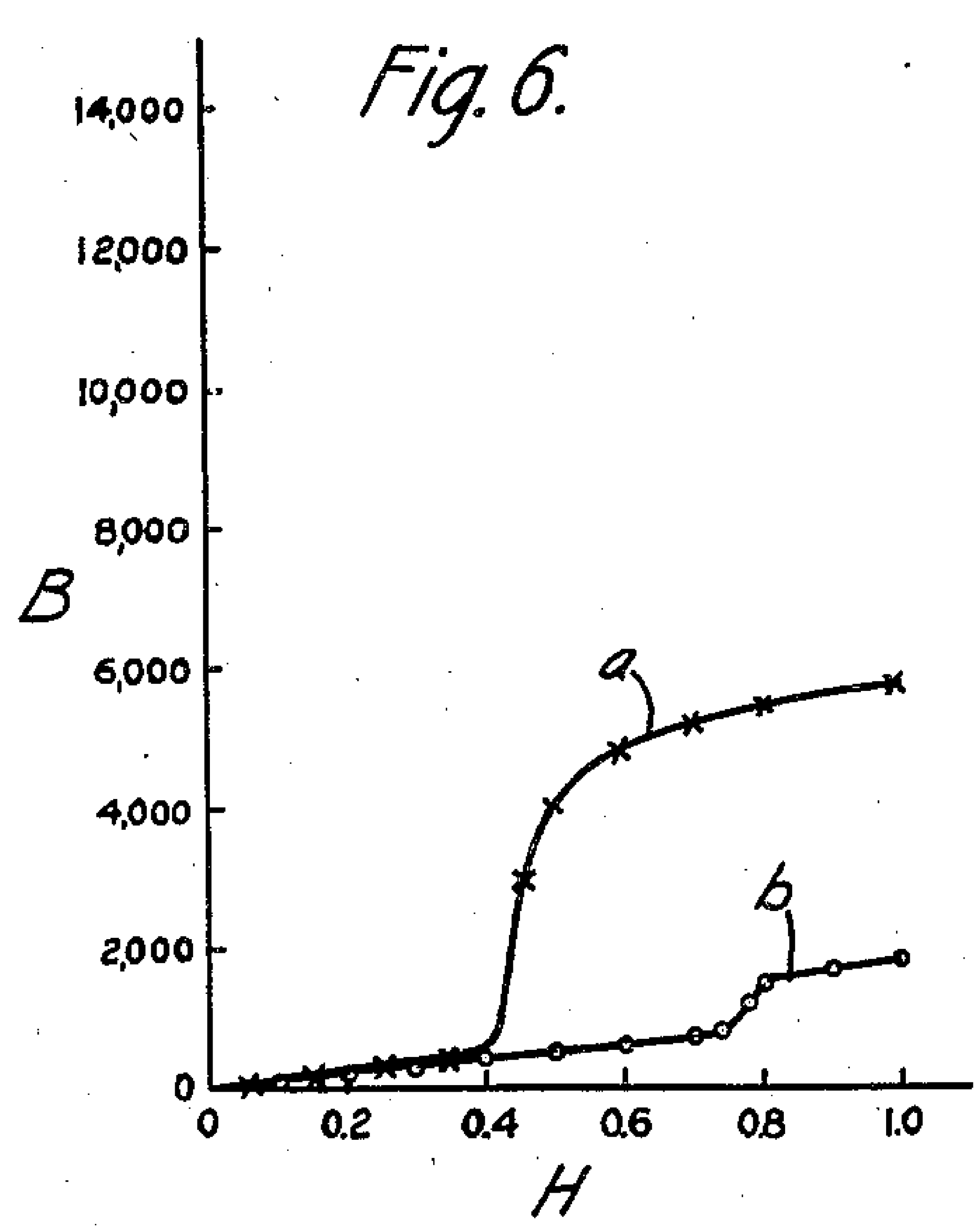
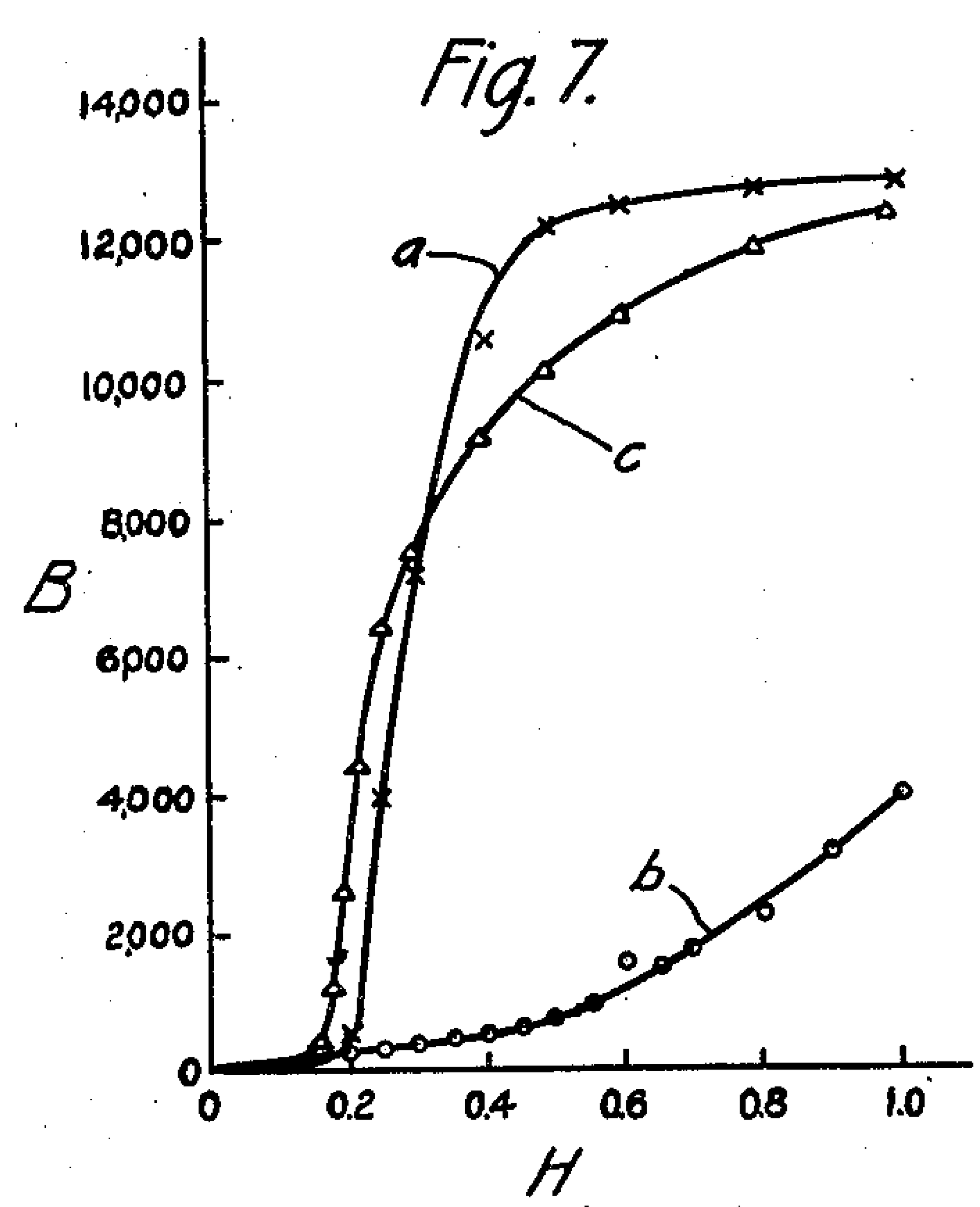


Fig. 7.



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MAGNETIC MATERIAL

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Fig. 8.

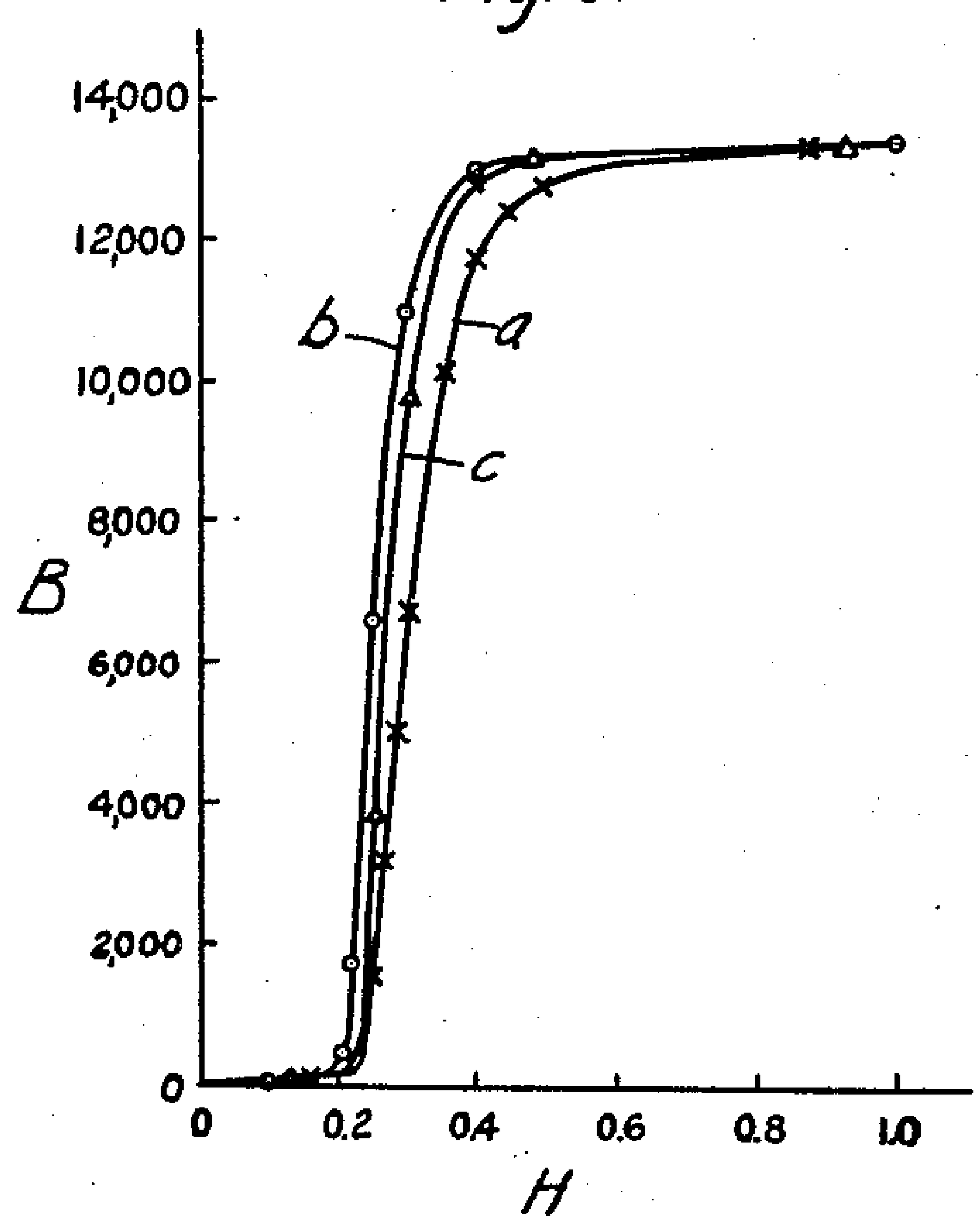


Fig. 9.

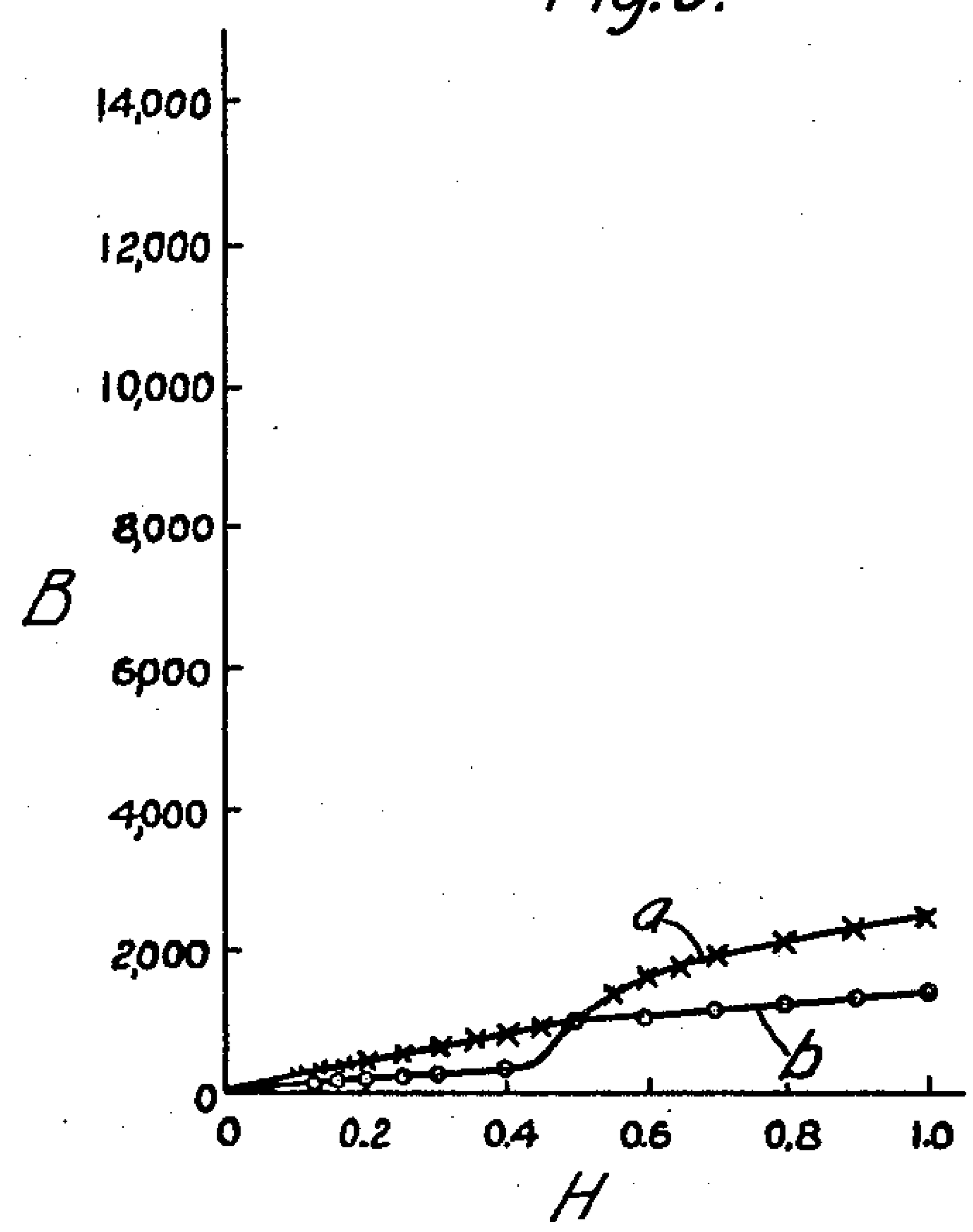
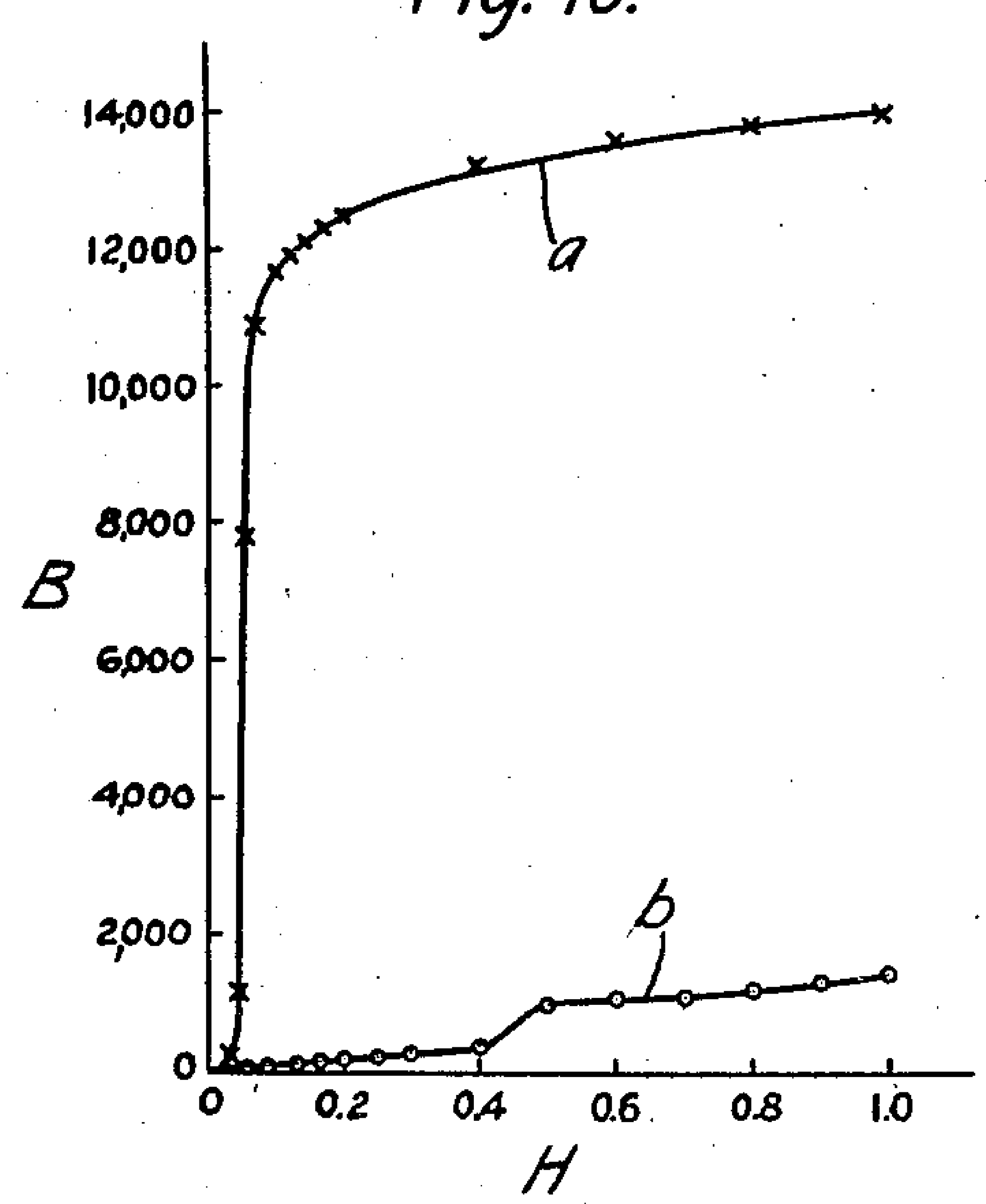


Fig. 10.



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MAGNETIC MATERIAL

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Fig. 11.

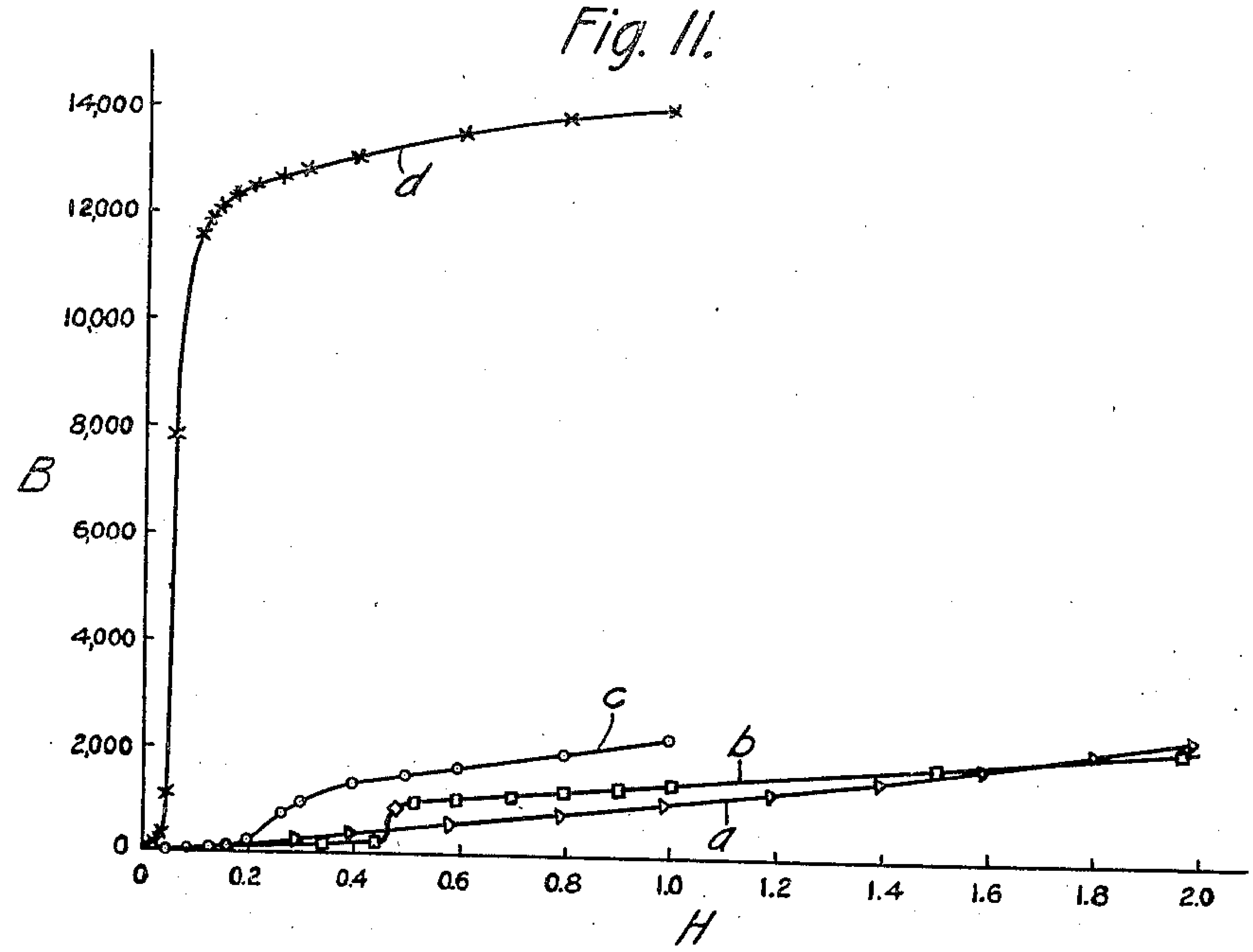
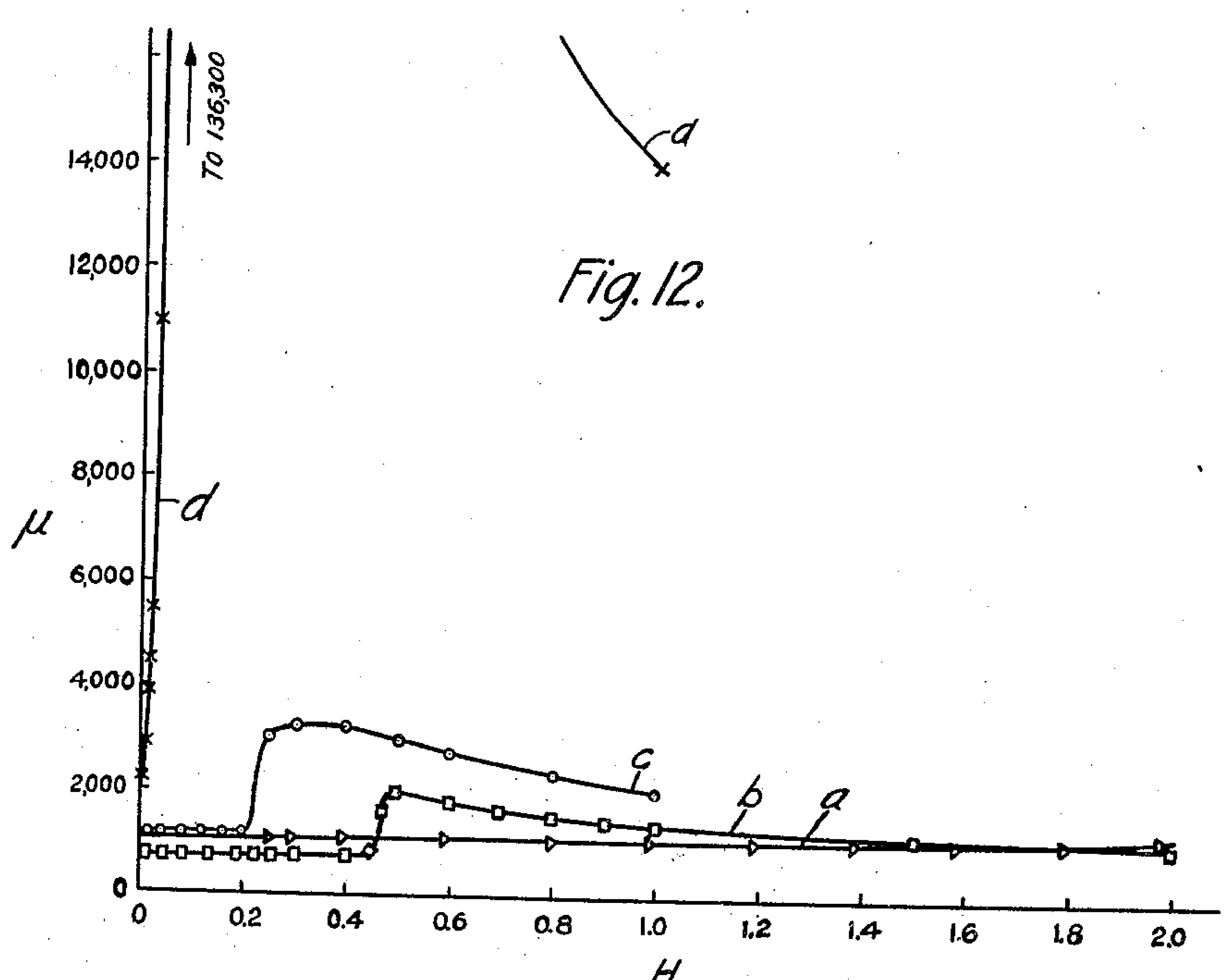


Fig. 12.



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MAGNETIC MATERIAL

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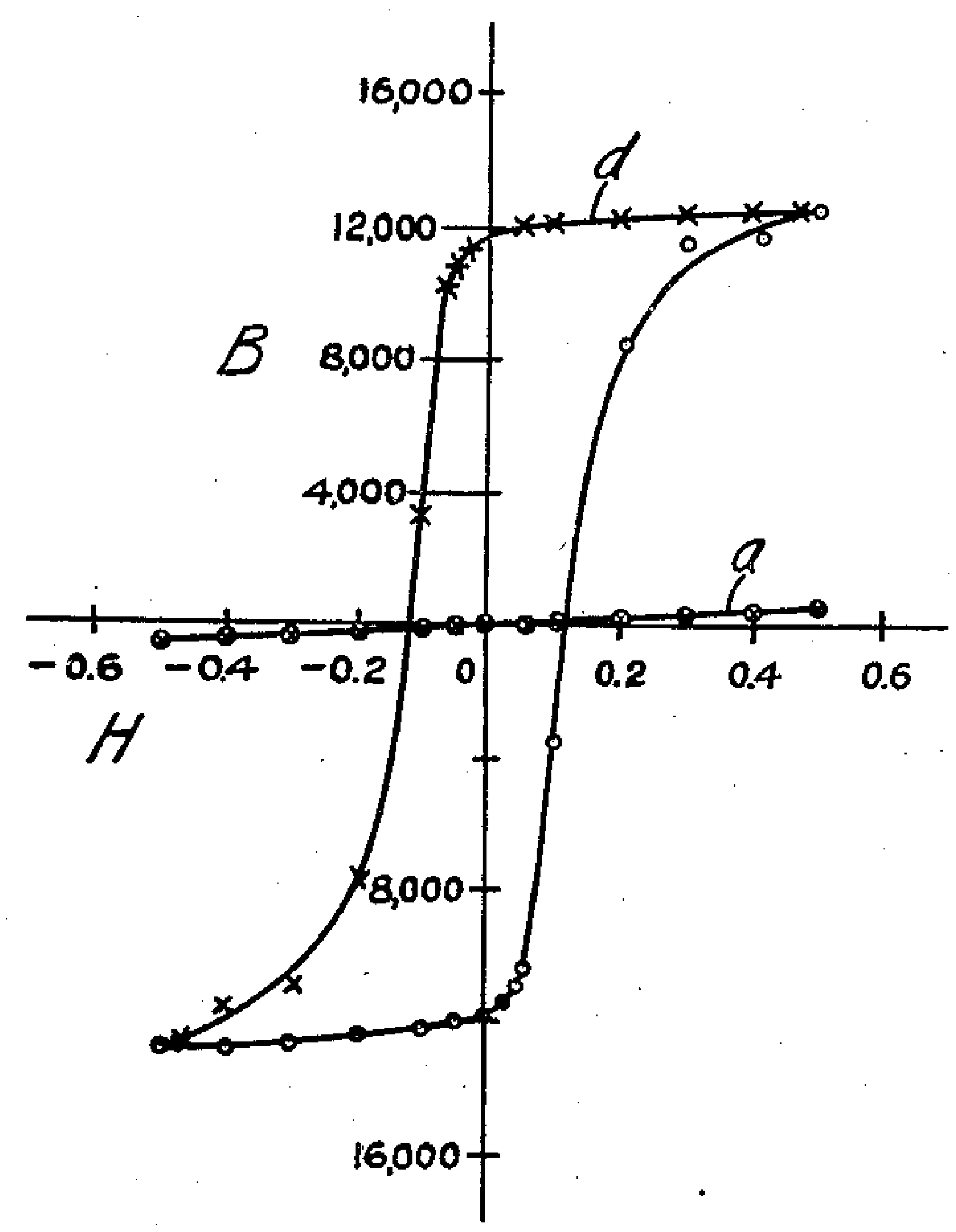

Fig. 13.

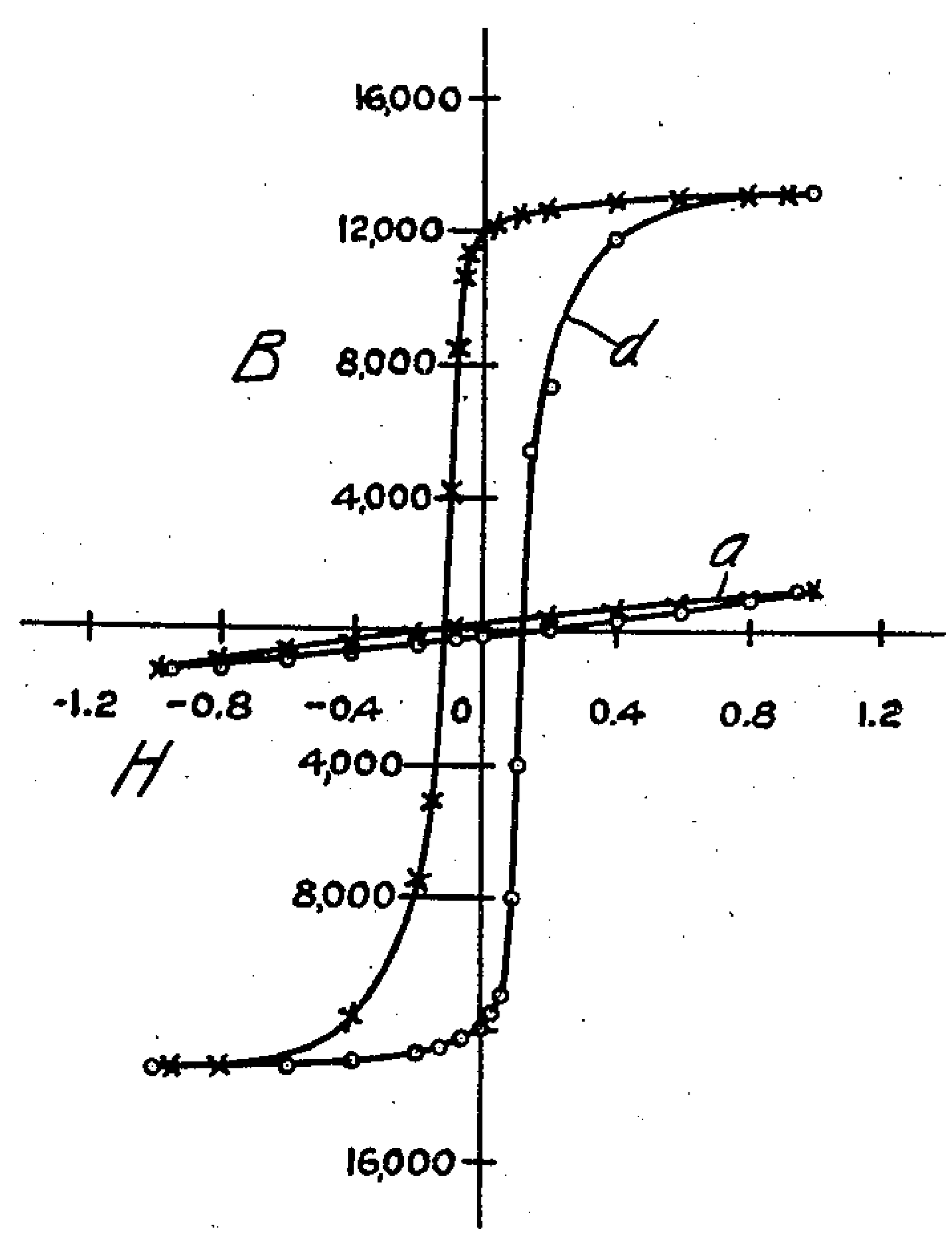

Fig. 14.

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Patented Apr. 16, 1929. **1,708,936**

UNITED STATES PATENT OFFICE.

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MAGNETIC MATERIAL.

Application filed December 23, 1926. Serial No. 156,615.

This invention relates to magnetic materials and particularly to a process for developing desired magnetic properties in such materials.

An object of the invention is to improve the magnetic properties of materials.

A specific object is to obtain substantially constant permeability in a magnetic material over a wide range of magnetizing forces.

While investigating the magnetic characteristics of nickel-iron-cobalt alloys, it was found that the relation between magnetizing force and magnetization varied considerably with changes in conditions to which the material was subjected while undergoing heat treatment. For instance, when the material was in the form of a flat spiral while being heat treated, the relation between magnetizing force and magnetization for a sample of nickel-iron-cobalt alloy was found to be substantially linear over a wide range of magnetizing forces. When straight samples of the same material were subjected to the same heat treatment, however, the magnetization curve was non-linear. It is believed as the result of extensive experiments that this difference in the magnetic characteristics of the material is due to the effect on the material of extraneous magnetic fields, such as that of the earth.

In accordance with the present invention in a broad aspect, a magnetic material in which a substantially linear relation between magnetizing force and magnetization exists and which, therefore, possesses a substantially constant permeability over a wide range of magnetizing forces and other desirable properties, is obtained by heating the material and subsequently cooling it in a space in which there is substantially no magnetic field tending to magnetize it in the direction of the magnetic axis which the material will have in use. In accordance with a specific embodiment of the invention, a method is provided for obtaining constant permeability and other desirable properties in a magnetic material consisting in applying magnetizing forces for counteracting the magnetizing effect of extraneous fields acting on the material during the heat treatment. For example, the material while being heat treated may be subjected to an applied field which is equal and opposite to the component of the earth's field tending to magnetize the material.

The characteristics of certain magnetic materials, other than constant permeability, obtained by substantially neutralizing the magnetic fields acting upon the material during heat treatment, are negligible hysteresis, remanence and coercivity. A particular magnetic material to which this invention is applicable consists of approximately 45% nickel, 25% cobalt and 30% iron with about 0.5% manganese added to increase the workability of the material. The curves given in Figs. 2 to 14 inclusive relate to specimens of this particular composition but are illustrative of the properties of other magnetic materials within the scope of this invention. In all of the figures of the drawing involving magnetizing forces and flux densities, these quantities are plotted in c. g. s. units.

The invention may be readily understood by referring to the following description and the drawing in which:

Fig. 1 is a schematic view of an apparatus which may be employed for subjecting a magnetic material to heat treatment in accordance with this invention.

Fig. 2 shows magnetization curves for straight and flat spiraled specimens of a nickel-iron-cobalt alloy.

Fig. 3 shows permeability curves corresponding to the curves of Fig. 2.

Fig. 4 shows magnetization curves for straight specimens of the alloy which were heat treated for various periods of time.

Fig. 5 shows magnetization curves for straight specimens of the alloy which were heat treated at various temperatures.

The curves of Fig. 6 show the effect on magnetization of slowly cooling the alloy from the maximum temperature employed in the heat treatment.

Fig. 7 shows magnetization curves for a straight specimen of the alloy which was subjected to alternate rapid and slow cooling.

The curves of Fig. 8 show the effect on permeability of reducing the cross section of a straight specimen of the alloy by etching.

Fig. 9 shows magnetization curves for straight specimens of the alloy which were cooled from the heat treating temperature at widely different rates.

Fig. 10 indicates the effect on the magnetization curves for a straight specimen of the alloy of adding a circular field to the field acting longitudinally in the material during the heat treatment.

Fig. 11 shows magnetization curves for straight specimens of the alloy which were heat treated in magnetizing fields of different intensity, respectively.

Fig. 12 shows permeability curves corresponding to the magnetization curves of Fig. 11.

And Figs. 13 and 14 show hysteresis loops for two of the specimens for which magnetization and permeability curves, respectively, are shown in Figs. 11 and 12.

Fig. 1 of the drawing shows an apparatus which may be employed for heat treating a magnetic material in accordance with this invention. The glass cylinder 20 is closed at one end and is provided at the other end with an air tight stopper 21 through which a metallic tube 22 passes. This tube is connected to a pump, not shown, for exhausting the air from the cylinder 20. One end of a specimen of magnetic material 23 which is to be heat treated is suitably attached to the metallic tube 22 at one end and a suitable weight 24 of conducting material is secured to the other end. This weight is electrically connected through the mercury column 26 with an electrode 25, which is sealed into the glass tube 20. A source of alternating current 35 is employed for heating the specimen of magnetic material 23. The magnitude of this heating current may be varied by means of the variable resistance 28 and measured by the meter 27. A winding 29 positioned about the cylinder 20 is employed to set up a magnetic field about the magnetic material 23 for substantially neutralizing the effects of other fields acting therein. The battery 30 supplies current to the winding 29, this current being varied by a variable resistance 31 and measured by a meter 32.

The curves of Figs. 2 and 3 indicate the difference in magnetic characteristics between two specimens of nickel-iron-cobalt alloy, one of which was in the form of a tape wound in a flat spiral and the other of which was in the form of a straight strip. This tape was 0.126″ wide and 0.006″ thick and the flat spiral specimens consisted of about 50 turns of this tape forming a loosely wound toroid 2.84″ inside diameter and 3.54″ outside diameter.

The heat treatments to which the specimens employed in obtaining the curves of Figs. 2 and 3 were subjected, were nearly identical and consisted in heating specimens in an electric furnace at a temperature of about 1100° C. for approximately one hour and then cooling at the rate of about 200° C. per hour. It was found that the flat spiraled specimen (curve *a* of Figs. 2 and 3) had a substantially constant ratio of flux density (B) to field intensity (H) and therefore a practically constant permeability for values of field strength up to nearly 3.0 gauss. On the other hand, in the case of the straight specimen (curve *b* of Figs. 2 and 3), it is indicated that the permeability increases rapidly with field intensity.

The specimens to which the remainder of the curves relate (except curve *a* of Fig. 10) were heat treated by suspending them vertically in a long cylinder, such as shown in Fig. 1, and passing a current therethrough. In this process sudden cooling is accomplished by opening the electrical circuit supplying the current while slow cooling is brought about by slowly decreasing the heating current. The temperature of the strip was measured by means of an optical pyrometer.

Fig. 4 shows the results of heat treating straight strips of the alloy at 1000° C. and 710° C. for various periods of time. The curves relating to the specimens heat treated at 1000° C. for 2, 6 and 20 minutes are designated respectively by *a*, *b*, and *c* of this figure and the curves relating to the specimens heat treated at 710° C. for the same periods are respectively resignated by *d*, *e* and *f*. The curves show that for the same heat treating temperature there are practically no differences in initial magnetization with respect to the time of heat treatment and only small differences are indicated for higher intensities of magnetization.

The curves of Fig. 5 indicate the effect of temperature of heat treatment on magnetic behavior. The specimens, to which the curves designated by the letters *a* to *h*, respectively, relate, were maintained at 1060° C., 1000° C., 970° C., 920° C., 850° C., 780° C., 710° C. and 640° C. for a period of two minutes after which the temperature was rapidly reduced to normal by opening the current supply circuit. These curves indicate that the magnetization goes on in two steps: an initially slow and almost linear change in flux with magnetizing force, followed by a rapid rise of flux for further small changes in magnetizing force. The initial permeability is low and is practically independent of the temperature of heat treatment as is indicated by the common portion of the curves in the initial stages of magnetization. The effect of increase in temperature is simply to shift the point of divergence from the common curve nearer to the axis of the ordinates. Thus, for a short time of heating by means of an electric current, followed by rapid cooling, a suggestion of the presence of linear magnetization with respect to magnetizing force is obtained, the region of linearity being smaller the higher the temperature of heat treatment.

The specimen to which curve *a* of Fig. 6

relates was maintained at a temperature of 1000° C. for two minutes and then cooled to room temperature in 14 minutes. The specimen to which curve *b* relates was heated to 710° C. for two minutes and also cooled to room temperature in fourteen minutes. The effect of slow cooling, as indicated by these curves, is to increase the range of field intensity over which the magnetization remains linear, this range being 0.4 gauss for the higher temperature of anneal and 0.7 gauss for the lower temperature. Although the initial permeability of the strip is much higher than that obtained with the flat spiraled specimen, the range over which the linear relation holds between magnetization and magnetizing force is considerably lower.

The curves of Fig. 7 are for a specimen which was subjected to alternate rapid and slow cooling from the same temperature. This specimen was first heated to a temperature of 1000° C. for two minutes and rapidly cooled. Curve *a* was then obtained, after which the specimen was again maintained at 1000° C. for two minutes and cooled to normal temperature in fourteen minutes. After obtaining curve *b* the specimen was again raised to a temperature of 1000° C., where it was maintained for two minutes, and then rapidly cooled. The data for curve *c* was then taken. The curves indicate that heating and slow cooling has a tendency to nullify the effect of heating and rapid cooling and vice versa. That the nullifying effect is not complete is indicated by the slight difference existing between curves *a* and *c* of Fig. 7 and between curve *b* of Fig. 7 and curve *b* of Fig. 6.

In order to determine if the effect of the cooling rate on the shape of the magnetization curve for the material was due to strains set up therein a specimen was heated, then cooled rapidly and tested, after which the surface layer of the specimen was removed by etching and the test repeated. If the magnetic behavior of the strip is affected by strains set up on the surface due to the rapid cooling, then the removal of the surface layer by etching should alter the magnetization. Curve *a* of Fig. 8 shows the magnetic characteristics of a straight specimen which was heated at 970° C. for two minutes and then rapidly cooled. The strip was then reduced in thickness from 0.006″ to 0.003″ by etching after which curve *b* was obtained. The data from which curve *c* is plotted was taken after a further reduction in thickness to 0.0015″. These curves indicate that the magnetic behavior of the strip is not appreciably affected by the removal of the surface layer of the material.

Fig. 9 shows the similarity in magnetic behavior that is obtained when employing wide differences in cooling rates. The specimens for which the curves of Fig. 9 were obtained were heat treated by being subjected to a temperature of 1000° C. and then slowly cooled. Curve *a* of this figure relates to a specimen which was maintained at this temperature for six minutes and cooled to normal temperature in fourteen minutes while the specimen to which curve *b* relates was raised to the same temperature where it was also maintained for six minutes and then cooled to normal temperature in 8.5 hours. These curves and the curves of Fig. 8 indicate that some cause other than strain in the material contributes toward the magnetic behavior of slowly cooled electrically heated strips.

The specimens with which the curves of Fig. 10 were obtained were heat treated by being subjected to a temperature of 1100° C. and then slowly cooled. The strip to which curve *a* relates was annealed in an electric furnace while the other strip to which curve *b* relates was heated by passing alternating current through the strip. It is believed that the difference in magnetic characteristic of the two specimens is due to the fact that the former was subjected, while being heat treated, to a component of the earth's field acting longitudinally in the strip and the latter was subjected both to this field and to a circular field produced by the heating current flowing through the strip. It appears that the atomic orientation obtained by the latter kind of magnetization at or near the Curie point would be sufficiently different to account for the difference in behavior brought about by the two methods of heat treating.

The curves of Fig. 11 show the relation between the field intensity and the resulting flux density for samples of the material which were heated to a temperature of about 1000° C. and slowly cooled while being subjected to various magnetizing fields. Curve *a* of this figure is for a sample which was suspended vertically while being heat treated and which was subjected to a magnetizing field substantially equal and opposite to the vertical component of the earth's field, thus neutralizing the magnetizing effect of the earth's field on the material. This curve indicates a linear relation between field intensity and flux density and, therefore, a constant value of permeability for flux densities below 2000. Curve *b* is for a sample of the material which was heat treated while under the influence of the vertical component of the earth's field acting longitudinally in the material, that is, the neutralizing field was not applied to this sample. A departure from the linear characteristics of curve *a* is indicated, there being an abrupt rise in flux density from about 300 to 1000 c. g. s. units for a change in field intensity from 0.4 to 0.5 gauss. Curve *c* shows the relation between flux density and field intensity for a sample of the material which was heat treated while being subjected to a magnetizing field twice as great as that of the vertical component of the earth's field acting in the longitudinal direction in the material, that is, the earth's field was supplemented by an equal artificially applied field. This curve indicates an abrupt rise in flux density at a value of field intensity of about 0.2 gauss. Curve *d* shows the results obtained with a sample which was heat treated with its longitudinal axis in line with the horizontal component of the earth's field. This curve rises from zero to a flux density of approximately 12,000 c. g. s. units for a change in field intensity from 0 to 0.1 gauss and then abruptly decreases in slope, rising from 12,000 to 14,000 c. g. s. units in flux density for a change in field intensity from 0.1 to 1.0 gauss.

Curves *a*, *b*, *c*, and *d* of Fig. 12 are permeability curves for specimens whose magnetization curves are designated as *a*, *b*, *c* and *d*, respectively, of Fig. 11.

Curves *a* and *d* of Fig. 13 and 14 are the hysteresis loops for the specimens whose magnetization and permeability curves are shown in curves *a* and *d*, respectively of Figs. 11 and 12. It is indicated by these curves that the effect of heat treating the specimen in a substantially neutral magnetizing field is to considerably decrease the hysteresis, remanence, and coercive force of the material. Curve *a* of Fig. 13 is a substantially straight line passing through the origin, a flux density of about 500 c. g. s. units being employed. When a higher flux density of approximately 1500 c. g. s. units is employed a small hysteresis loop is obtained as shown in curve *a* of Fig. 14.

In comparing the various curves, we find that a magnetic material characterized by a linear relation between field intensity and flux density, that is to say, by a constant value of permeability over a wide range of magnetizing forces is obtained by subjecting the material to a heat treatment while at the same time preventing magnetization of the material. Other magnetic properties simultaneously developed by this treatment are negligible remanance, negligible coercive force and the absence of hysteresis. One method of preventing the magnetization of the material is to subject it to an artificially applied magnetizing field which is equal and opposite to any field acting within the material tending to magnetize it. However, other methods of preventing the magnetization of the material during the heat treatment may be employed as, for example, shielding the material from extraneous fields by surrounding it with a magnetic enclosure.

It has been found, moreover, that cross magnetization during heat treatment, that is magnetization in a direction substantially perpendicular to the magnetic axis which the material will have in use, does not affect the desired magnetic properties which are obtained in accordance with this invention. It is therefore within the scope of this invention in a broad aspect to obtain constant permeability and other magnetic properties mentioned above by heating the magnetic material in a space in which there is substantially no magnetizing field tending to magnetize it in the direction of the magnetic axis the material will have in use.

What is claimed is—

1. The method of obtaining substantially constant permeability in a nickel-iron-cobalt alloy over a wide range of field intensities, which consists in heating the alloy and subjecting it while cooling to a field for substantially neutralizing the magnetizing effect of extraneous fields acting on the alloy.

2. The method of increasing the constancy of permeability in a substantially straight sample of magnetic material which consists in suspending the material in a substantially vertical direction, passing a heating current through said material, subsequently gradually reducing said heating current to zero and simultaneously subjecting said material to a magnetic field equal and opposite to the vertical component of the earth's field.

3. The method of obtaining in a magnetic alloy composed of approximately 45% nickel, 25% cobalt and 30% iron, substantially constant permeability over a wide range of magnetizing forces, which consists in heat treating the alloy and at the same time applying a magnetic field thereto for reducing the magnetizing effect of other fields acting on the alloy.

4. The method of improving the magnetic properties of an alloy containing as essential constituents, iron, nickel and cobalt, which consists in heating the alloy and subjecting it to the action of an artificially applied magnetic field while it is being cooled.

5. The method of reducing any or all of the coercive force, remanent magnetism, or hysteresis loss, in a magnetic material including as essential constituents, iron, nickel and cobalt, which comprises heating the material and cooling it in a space in which the field acting to magnetize the material is reduced to a value which is a small fraction of the earth's field.

In witness whereof, I hereunto subscribe my name this 14th day of December A. D., 1926.

PAUL P. CIOFFI.