

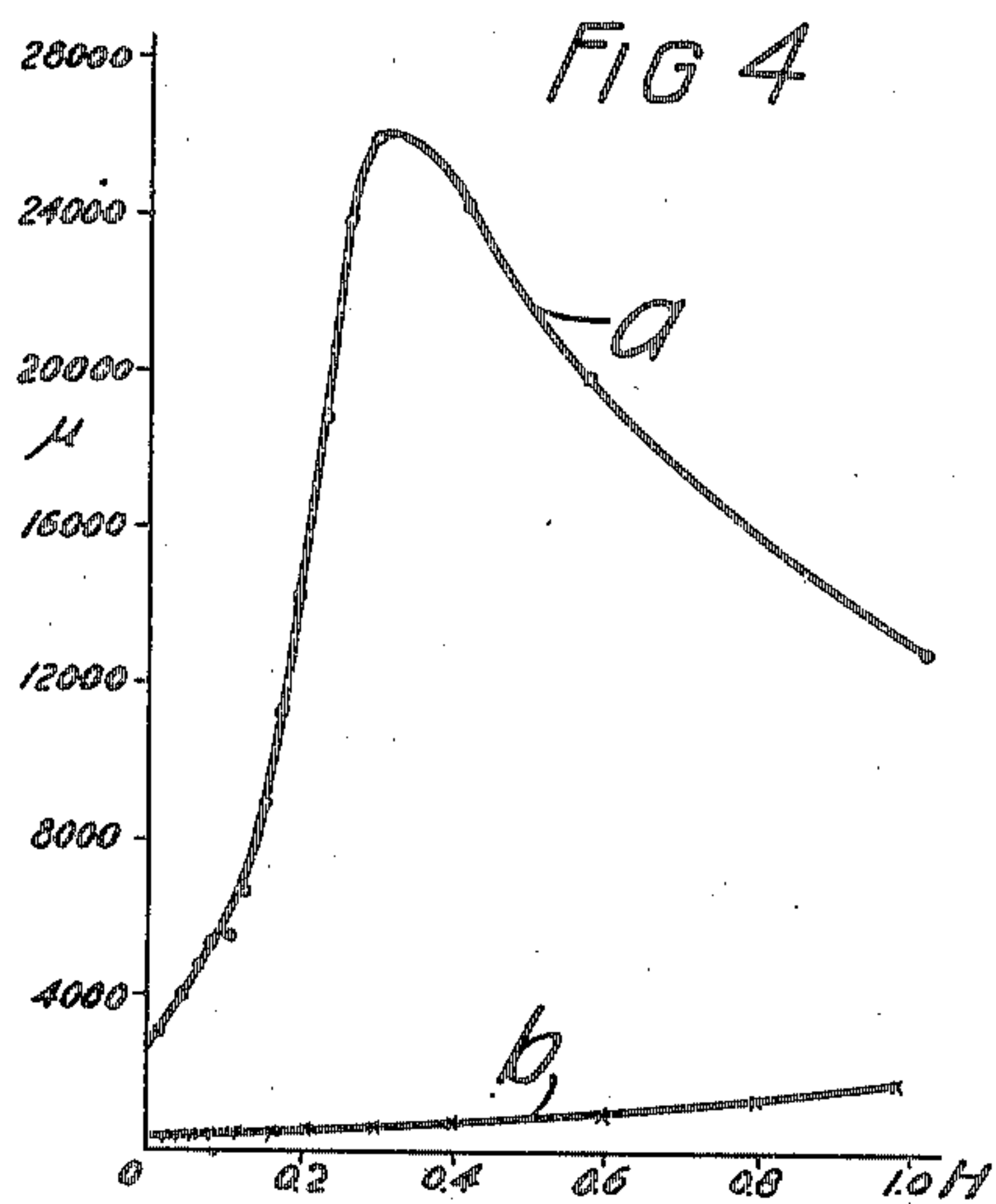
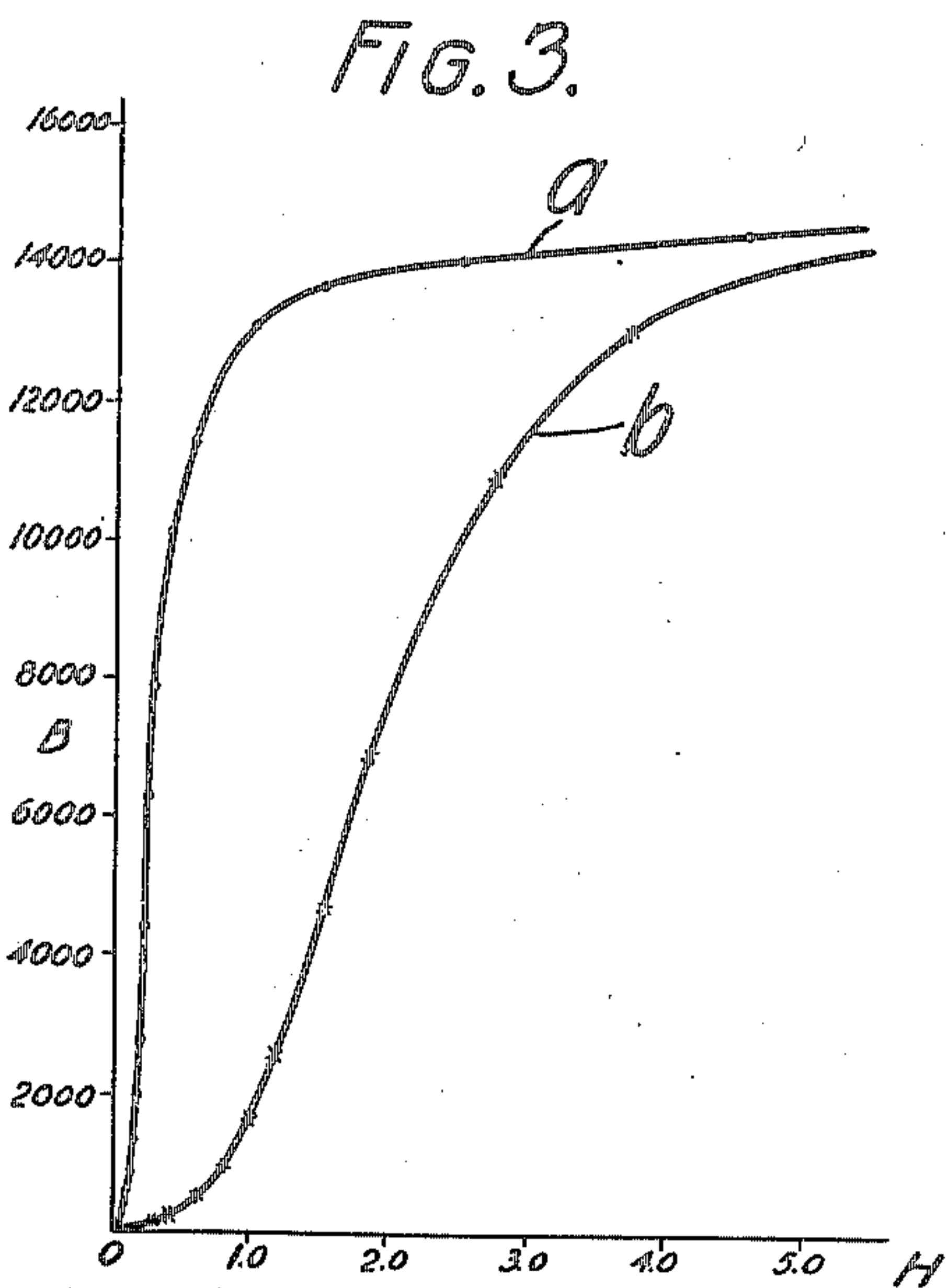
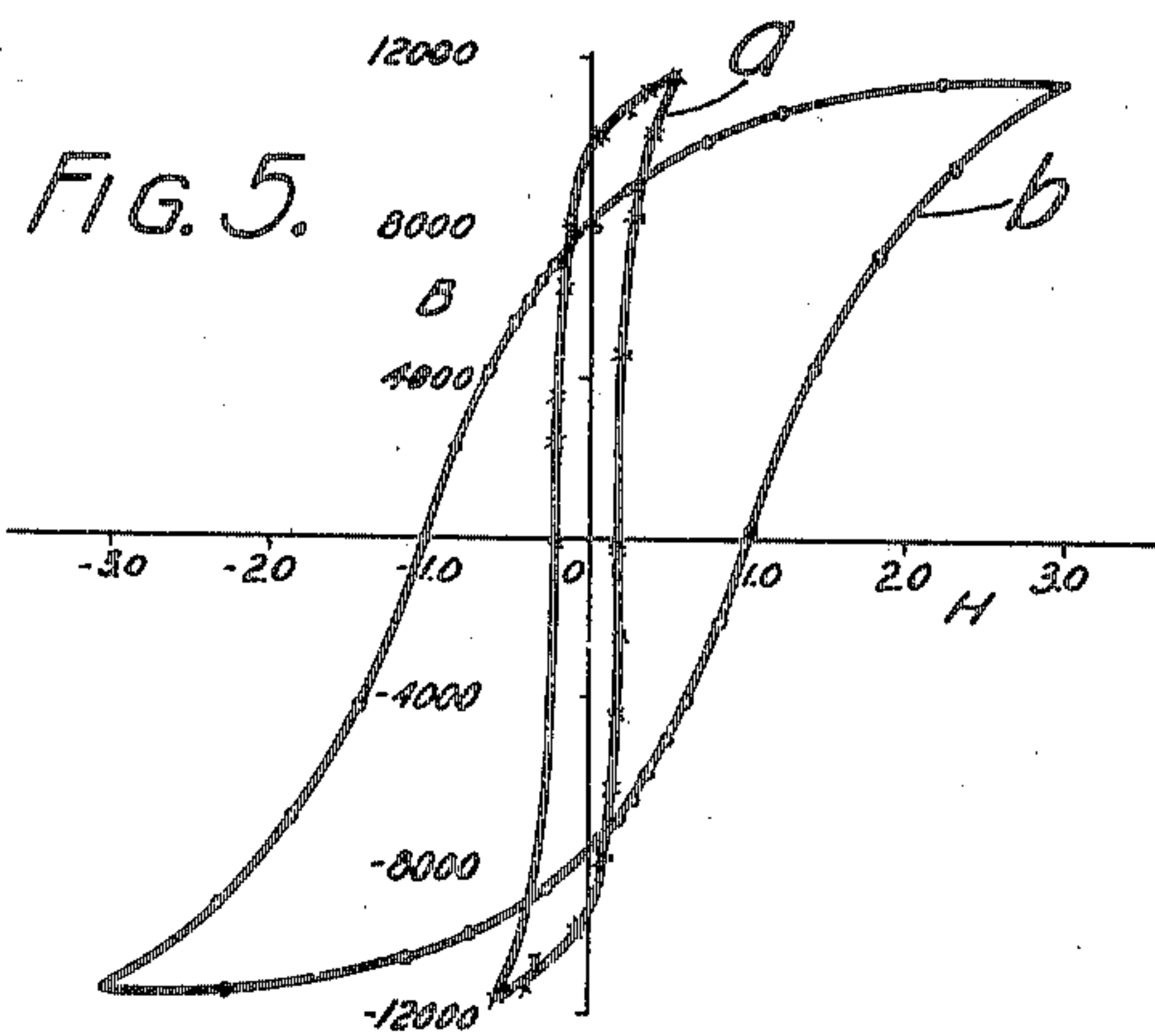
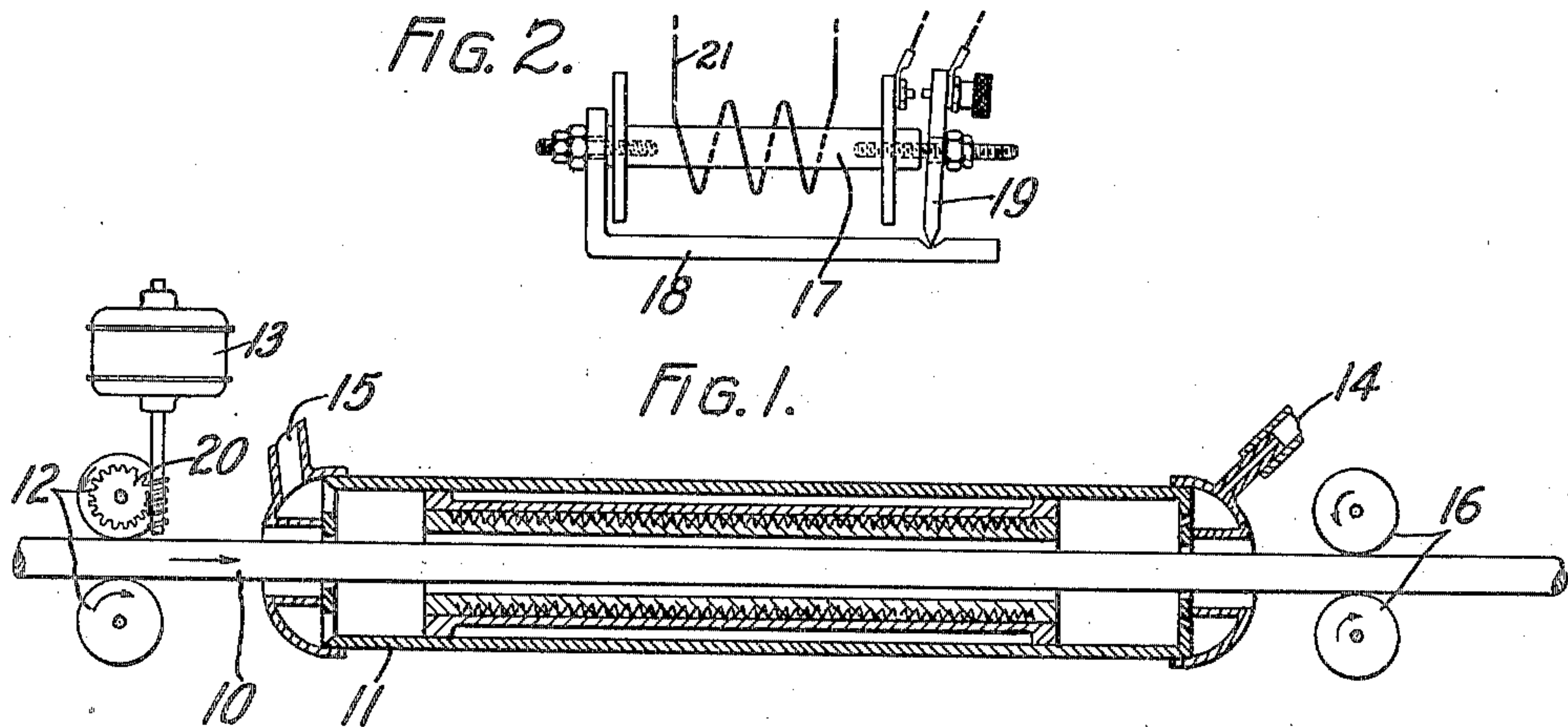
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METALLIC ELEMENT

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METALLIC ELEMENT

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This invention relates to metallic elements, particularly to such elements for use in magnetic circuits of electromagnetic devices and systems, and to a method for producing such elements.

The invention has one of its embodiments in an element of a magnetic circuit, which element comprises essentially a single large crystal of iron. This embodiment of the invention which is described in detail below, may be regarded as being typical of other embodiments which include elements formed of iron alloys, cobalt, cobalt alloys and other polymorphic metals, that is, metals having a different crystal structure above than below a temperature known as the transformation temperature.

The method of producing such elements in accordance with this invention comprises establishing a steep temperature gradient in the metal over a range within which lies the transformation temperature, and causing the region of steep temperature gradient to move through the metal at a rate equal to or less than the rate of crystal growth. If the rate at which the region at the transformation temperature moves through the metal is too great the transformation may not be completed and the crystal structure appropriate to higher temperatures may be in part preserved at low temperatures.

The advantages which are gained by employing in magnetic circuits monocrystalline iron in place of ordinary iron having a polycrystalline structure are due to the relatively high permeability of the former over a wide range of magnetizing forces and its lower hysteresis loss. An alloy composed of approximately 78½% nickel and 21½% iron suitably heat treated as disclosed in Patent No. 1,586,884, granted to G. W. Elmen, June 1, 1926 has higher permeability and lower hysteresis than ordinary iron at low values of magnetizing force. The monocrystalline iron made in accordance with this invention, while not so good in these respects as this alloy, has the advantage thereof of having high permeability and low hysteresis loss compared with polycrystalline iron at relatively high values of magnetic induction.

The monocrystalline iron and polycrystalline iron saturate at about the same value of induction which is considerably higher than the induction at which the nickel-iron alloy saturates. The mechanical properties of monocrystalline metals also differ substantially from those of ordinary metals having a polycrystalline structure. Although a monocrystalline metal is mechanically weaker than a polycrystalline metal, it is not so subject to defects of elasticity commonly called elastic after-effects and fatigue. The substitution of monocrystalline for polycrystalline iron or other metal is, therefore, sometimes of advantage in places where magnetic properties are not important.

Metals as ordinarily prepared consist of a large number of small crystals, from about 100,000 to several million in a cubic inch. This results from the fact that under ordinary conditions when the metal freezes, or when it passes through a temperature transformation, crystallization takes place at a large number of centers and these crystals grow until they meet one another.

The process of producing large crystals in accordance with this invention avoids difficulties heretofore encountered and is sufficiently reliable to make possible the commercial production of large crystals of polymorphic metals, such as iron. Iron, for example, changes its crystal structure from face-centered cubic to body-centered cubic when the temperature of the iron is decreased through the transformation temperature at approximately 900° C. The present process also succeeds where the previous methods fail, for instance, in the case of iron containing any appreciable amount of carbon.

The invention may be readily understood by referring to the following detailed description in connection with the accompanying drawing in which,

Fig. 1 is a diagrammatic view of an apparatus which is suitable for producing large crystals in accordance with this invention;

Fig. 2 is a diagrammatic view of a relay, a large portion of the magnetic circuit of which consists of iron in the form of a single large crystal;

Fig. 3 shows for comparison magnetization curves for samples of monocrystalline and polycrystalline iron, otherwise alike;

Fig. 4 shows permeability curves for the samples of iron employed in obtaining the curves of Fig. 3; and

Fig. 5 shows hysteresis loops for the samples of iron employed in obtaining the curves of Figs. 3 and 4.

Referring now to Fig. 1 of the drawing, the ordinary polycrystalline iron rod 10 is passed into the electric furnace 11 in the direction indicated by the arrow by means of the rollers 12 which are driven by the electric motor 13 through the worm and pinion gear 20 and is guided at the opposite end of the furnace by the rollers 16. The furnace temperature is maintained sufficiently high to heat a part of the rod to a temperature higher than the transformation temperature (approximately $900^{\circ}\text{C}.$) at or just below which will grow iron crystals of the body-centered cubic form stable at room temperature, a preferred temperature for the hottest part of the rod being about $1400^{\circ}\text{C}.$ As the iron rod passes out of the furnace, it is cooled by conduction to the rollers 16 and by a stream of hydrogen or other suitable gas which flows in through the opening 14, then through the furnace 11, and out through the opening 15. There is thus established in the iron rod as it passes out of the furnace 11 a steep temperature gradient which includes the temperature for growing iron crystals referred to above. This means that two points in the rod not widely separated in the longitudinal direction may have respectively a temperature as high as $1400^{\circ}\text{C}.$ and a temperature as low as $100^{\circ}\text{C}.$ or $200^{\circ}\text{C}.$ Only a very small portion of the rod measured in the direction of its length is, therefore, at the optimum crystal-growing temperature of about $900^{\circ}\text{C}.$ at a given time. The rod is passed through the oven at a rate equal to or less than the rate at which the body-centered cubic iron crystals grow. This rate has not been definitely established but good results have been obtained by employing a rate equal to 200 centimeters per hour and less although it is possible that rates higher than this value are practicable. It is apparent that, when the steep temperature gradient just mentioned is maintained in the rod and the rate at which the rod passes through this region of steep temperature gradient is equal to or less than the rate of crystal growth, the rod will have the form of a single crystal when it passes out of the heating and cooling apparatus. The hydrogen besides cooling a portion of the rod helps to prevent the oxidation thereof and to aid in removing carbon which always increases hysteresis in magnetic material.

After the rod passes through the rollers 16, it may be cut into lengths suitable for use in magnetic circuits such as that of the relay shown in Fig. 2. In this relay the core 17 on which the winding 21 is positioned comprises essentially a single iron crystal of the body-centered cubic form such as obtained by the process described in connection with Fig. 1. The magnetic circuit is completed through the return magnetic path 18 and the armature 19. The use of monocrystalline iron or other magnetic materials in the monocrystalline form is advantageous not only in the magnetic circuits of relays, but also in other devices in which high permeability and low hysteresis loss are desired and which are to be operated at magnetic inductions nearly up to the saturation point of iron, this point being about the same for both the single crystal and the polycrystalline iron.

The magnetic characteristics of samples of monocrystalline iron and polycrystalline iron are shown respectively by the curves *a* and *b* of Figs. 3, 4 and 5, these curves being plotted in c. g. s. units. The two samples compared were of the same chemical composition and were treated as nearly as possible in the same way consistently with obtaining the difference in crystal size. The curves of Fig. 3 indicate that both the monocrystalline iron (curve *a*) and the polycrystalline iron (curve *b*) saturate at approximately the same value of magnetic induction (*B*). The monocrystalline iron saturates comparatively sharply reaching a value of $B=13000$ at a value of magnetizing force of $H=1.0$ while the polycrystalline iron reaches the same value of *B* at a value of $H=3.75$.

Fig. 4 shows that the permeability (μ) of monocrystalline iron (curve *a*) is high compared with that of the polycrystalline iron (curve *b*) over a range of magnetizing forces. The monocrystalline iron has an initial permeability of approximately 2000 and a maximum permeability of about 26000. Moreover, the permeability of this material is appreciably higher than that of the polycrystalline iron for values of *H* from zero to a value well above 1.0 gauss, the permeability for $H=1.0$ gauss being 13000 compared with a permeability of about 2000 for the polycrystalline iron.

Fig. 5 shows hysteresis loops for the two types of iron. It is apparent that the area of the hysteresis loop for the monocrystalline iron (curve *a*) is considerably less than that of the polycrystalline iron (curve *b*).

While the process described above for making the monocrystalline metal employs an electric furnace, it is apparent that other methods of obtaining a high temperature gradient in the metal may be employed. For example, electrical current may be passed

through the rod itself by providing it at suitable points along its length with sliding or rolling electrical contacts to which a source of heating current is connected. It is also apparent that, while the process described above employs a rod of uniform circular cross-section and a furnace at a constant temperature, pieces of metal having other forms of cross section or having irregularities in cross section may be treated in accordance with this invention by suitably varying the shape of the furnace, the temperature to which it is heated or the rate at which the metal is propelled through it.

What is claimed is:

1. A process for growing large crystals in a material the structure of which changes from one type of crystal to another at a temperature well below its melting point, which process comprises establishing a steep temperature gradient in the material such that at a certain position within the region of said temperature gradient the material is at a temperature at which said change in crystal structure occurs, and causing the region of steep temperature gradient to move through the material at a rate not greater than the rate of growth of the crystals which are stable below said temperature.

2. A process for producing a metallic element a large portion of which is in the form of a single crystal, which process comprises establishing a steep temperature gradient in a magnetic material having a polymorphic transformation such that at a certain position within the region of said temperature gradient the material is at a temperature at which the crystal structure changes from one type of crystal into another, and causing the region of steep temperature gradient to move through the material at a rate not greater than the rate of growth of crystals which are stable below said temperature.

3. A process for producing a magnetic element in a material having allotropic modifications and comprising a single crystal from a metallic blank formed of numerous small crystals, which process comprises progressively subjecting small portions of said metallic blank first to a temperature below the melting point of the metal and well above the temperature at which said single crystal is formed and then to a temperature well below the temperature at which said single crystal is formed.

4. A process for producing a magnetic element comprising a single crystal from a metallic blank formed of a material having allotropic modifications, which process comprises progressively subjecting small portions of said metallic blank first to a temperature below the melting point of the metal and well above the temperature at which said single crystal is formed and then to a temperature well below the temperature at

which said single crystal is formed, and causing a non-oxidizing atmosphere to come in contact with first the cooled portion and then the heated portion of said metallic blank.

5. A process for producing a magnetic element comprising a single crystal from a polycrystalline metallic blank, which process comprises progressively subjecting small portions of said metallic blank first to a temperature below the melting point of the metal and well above the temperature at which said single crystal is formed and then to a temperature well below the temperature at which said single crystal is formed, and passing hydrogen about said blank from the cooled region toward the heated region.

6. A process for producing an iron element comprising a single magnetic crystal from an iron blank comprising numerous small crystals, which process comprises passing the blank through a high temperature region and a low temperature region, respectively, at a rate not greater than the rate of growth of an iron crystal of the body centered cubic form, the portion of the blank in said high temperature region being subjected to a temperature well above 900° C. while the portion of the blank in said low temperature region is subjected to a temperature well below 900° C.

7. A process for producing an iron element comprising a single magnetic crystal from an iron blank comprising numerous small crystals, which process comprises passing the blank through a high temperature region and a low temperature region respectively, at a rate equal to or less than the rate of growth of iron crystals of the body centered cubic form, the portion of the blank in said high temperature region being subjected to a temperature well above 900° C. while the portion of the blank in said low temperature region is subjected to a temperature well below 900° C., and passing a stream of hydrogen about said blank from the low temperature region toward the high temperature region for cooling the blank and for preventing its oxidation respectively.

8. A process for producing an iron element comprising a single magnetic crystal from an iron blank comprising numerous small crystals, which process comprises providing a high temperature region for raising the temperature of a portion of the blank to approximately 1400° C. and a low temperature region for cooling a portion of the blank adjacent to said heated portion to a temperature well below 900° C., and passing said blank through said high temperature and low temperature regions in order respectively at a rate not greater than the rate at which body centered iron crystals are formed.

9. A process for producing an iron element comprising a large magnetic crystal from an iron blank comprising numerous small crystals

tals, which process comprises providing a high temperature region for raising the temperature of a portion of the blank to approximately 1400° C. and a low temperature region for cooling a portion of the blank adjacent to said heated portion to a temperature well below 900° C., passing said blank through said high temperature and low temperature regions in order respectively at a rate not greater than the rate at which body centered iron crystals grow, and passing a stream of hydrogen about said iron blank from said low temperature region toward said high temperature region.

10. The method of growing large crystals in a material that has a polymorphic change in crystal structure below its fusing point, which comprises heating one region of the material to a temperature above the optimum temperature for growth of crystals stable at room temperature, cooling it well below said optimum temperature at a very closely adjacent region whereby a narrow region of steep and falling temperature gradient occurs, and causing said material to move continuously in a direction from the heated region toward the cooled region at such a rate that in the region of steep falling temperature gradient a continuous recrystallization occurs.

In witness whereof, I hereunto subscribe my name this 11th day of April A. D., 1927.

LOUIS W. McKEEHAN.