

June 4, 1929.

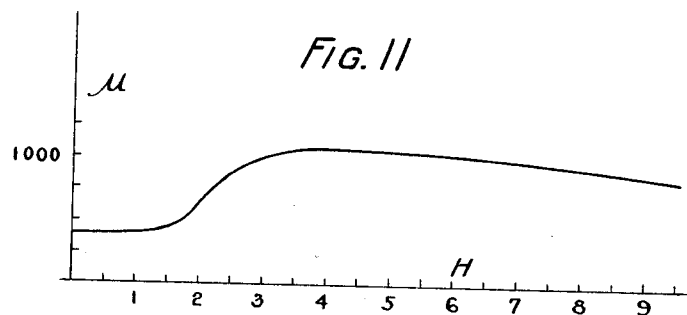
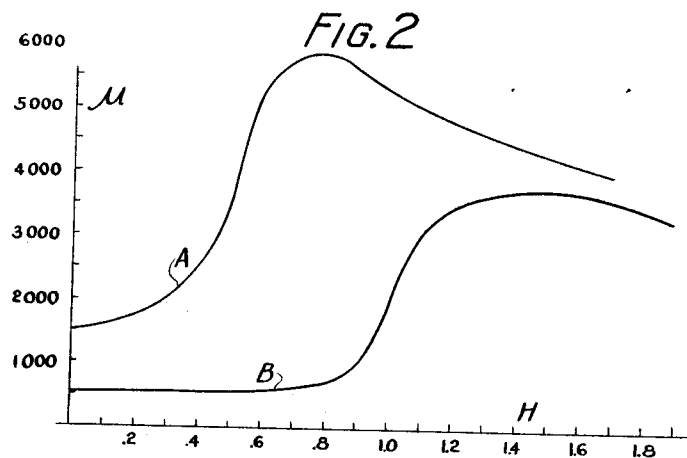
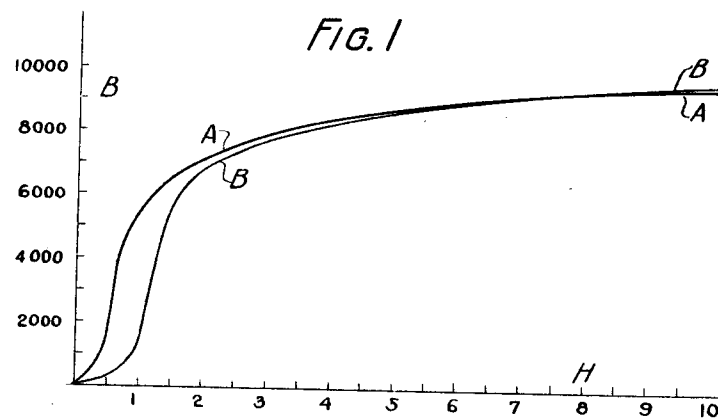
G. W. ELMEN

1,715,541

MAGNETIC MATERIAL

Filed Sept. 19, 1927

7 Sheets-Sheet 1



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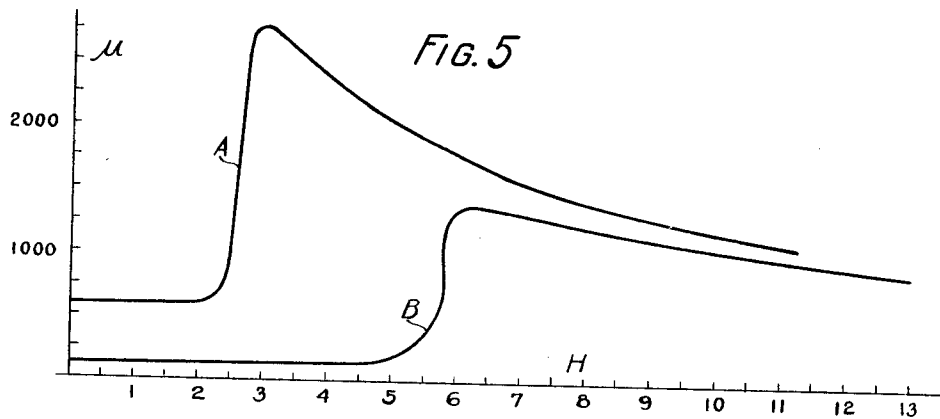
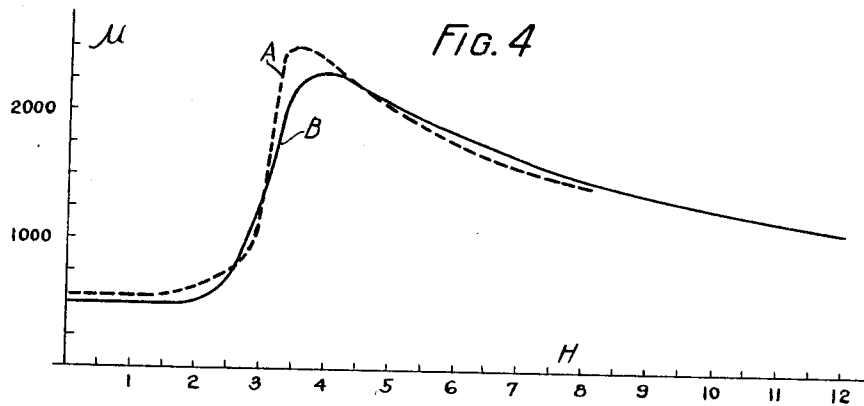
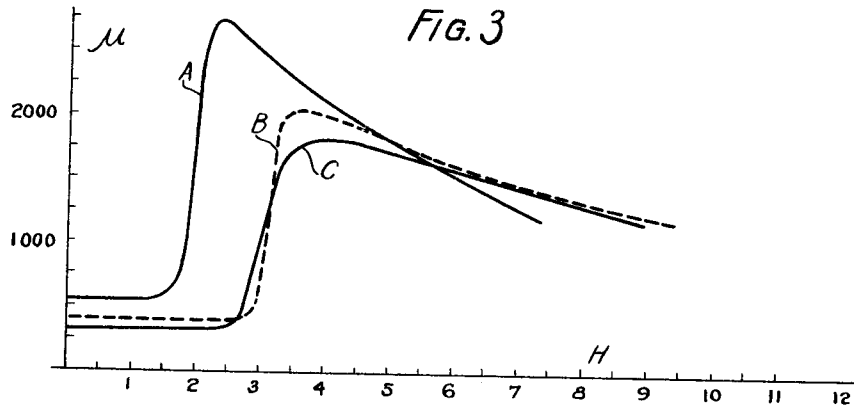
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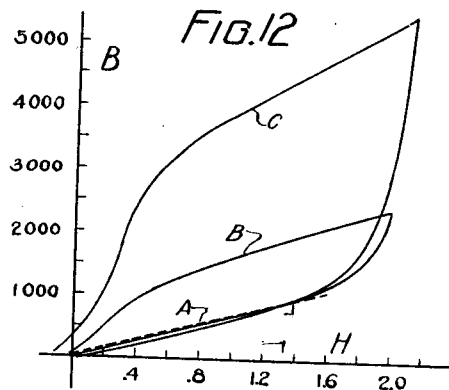
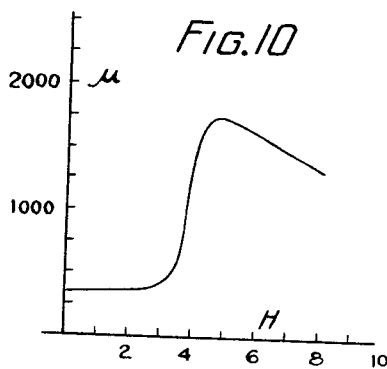
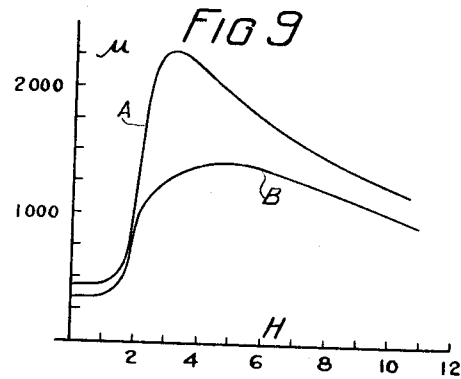
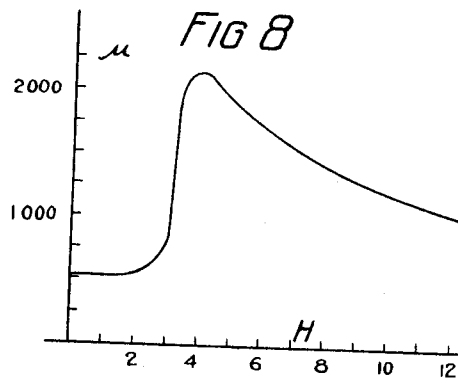
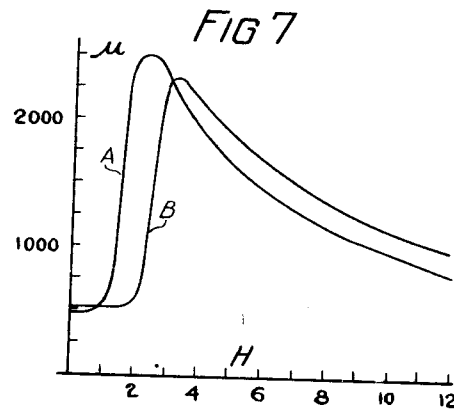
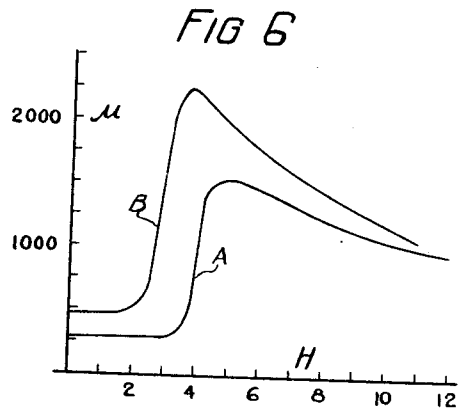
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7 Sheets-Sheet 3



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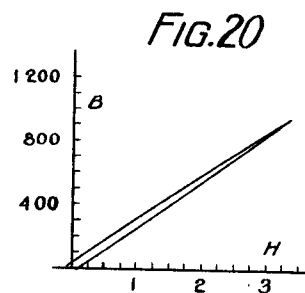
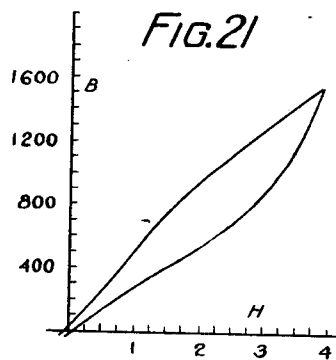
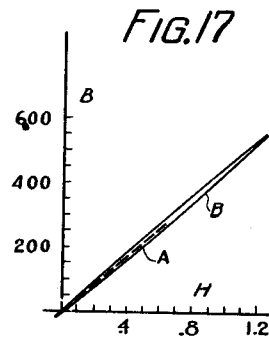
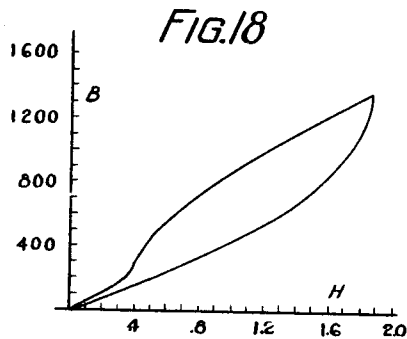
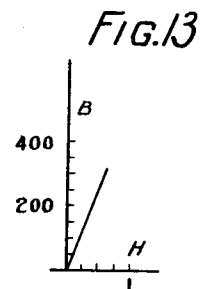
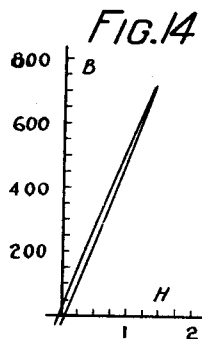
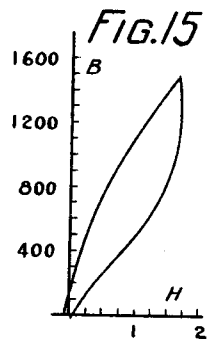
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7 Sheets-Sheet 4



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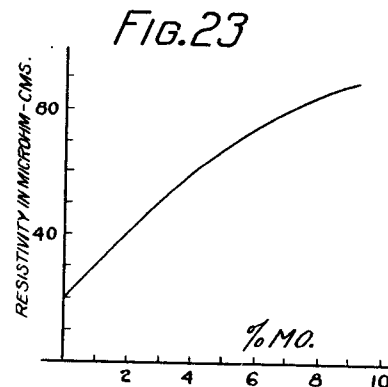
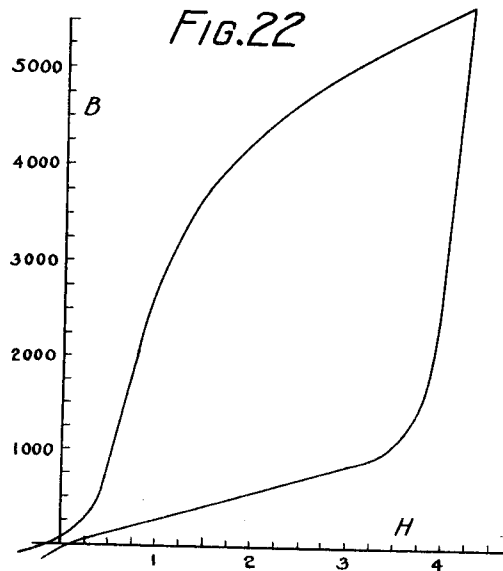
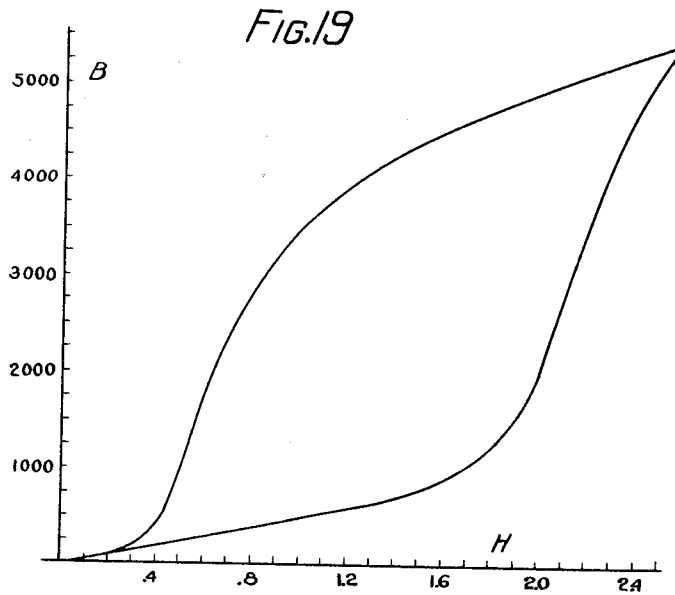
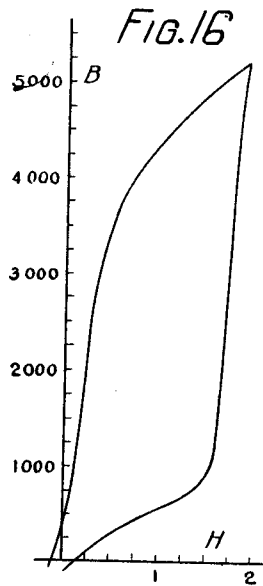
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MAGNETIC MATERIAL

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7 Sheets-Sheet 5



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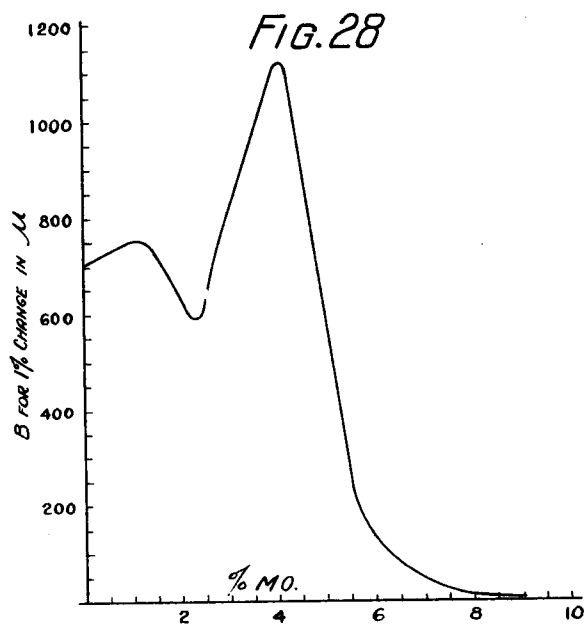
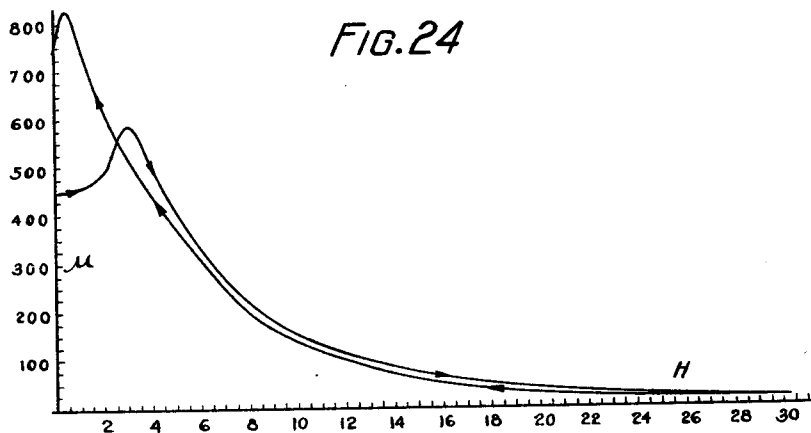
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MAGNETIC MATERIAL

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7 Sheets-Sheet 6



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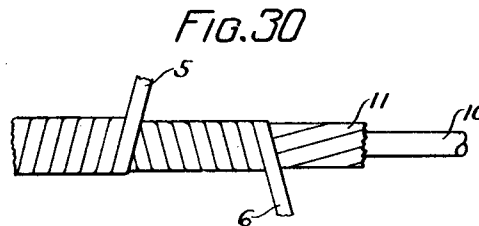
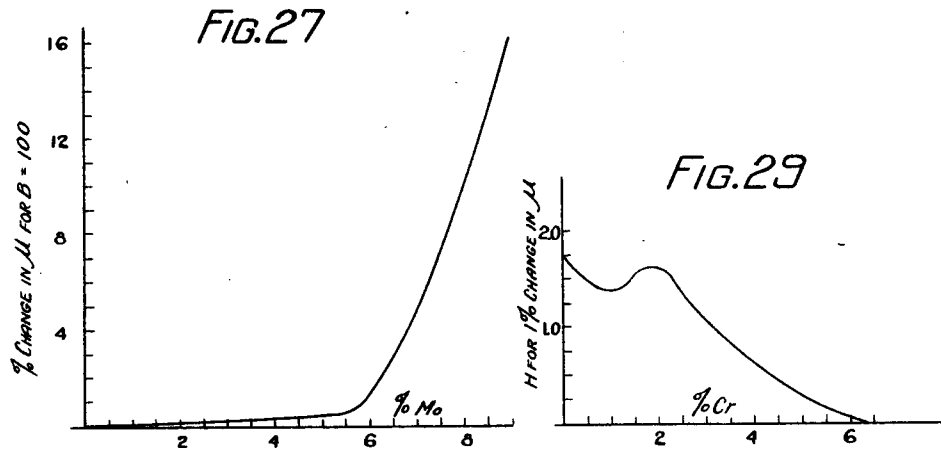
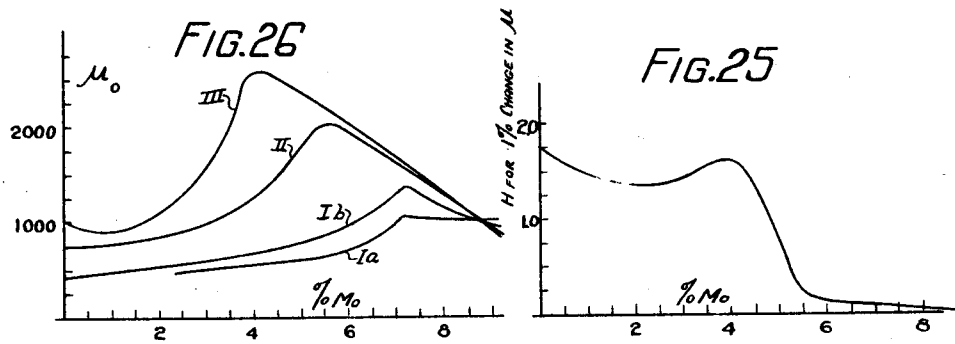
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UNITED STATES PATENT OFFICE.

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MAGNETIC MATERIAL.

Application filed September 19, 1927. Serial No. 220,387.

The present invention relates to magnetic materials and to their application to electromagnetic systems. It has a wide field of usefulness and is of special interest in all those cases in which the impressed magnetizing forces are small, such as in electric signaling systems.

Among the more important characteristics of the materials of this invention are high permeability, especially at low magnetizing forces, high degree of constancy of permeability over a considerable range of magnetizing forces, and high resistivity with consequent low eddy current losses.

In Elmen's U. S. Patent 1,586,884, June 1, 1926 there are described and claimed methods of producing nickel-iron alloys of high permeability and low hysteresis loss at magnetizing forces employed in the magnetic circuits of loaded communication circuits. In U. S. Patent 1,586,883, June 1, 1926 and other of applicant's patents and applications, there are described similar compositions, and methods of producing them, which have the additional valuable property, among others, of high resistivity imparted to them by the addition of a third element.

In Elmen's application, Serial No. 119,623, filed June 30, 1926, there are described and claimed magnetic compositions of iron, nickel, and cobalt which have been discovered to have, among other unusual properties, a very high degree of constancy of permeability over a wide range of magnetizing forces including the low range employed in loaded signaling conductors. The utility of such compositions may be increased, especially for loading speech frequency or other high frequency circuits, by increasing their resistivity, if this be done without excessively or at all impairing other desirable properties.

Brief mention is made in that application of the addition of fourth substances such as chromium to increase the resistivity. It is in this present specification, however, that compositions including added fourth substances to increase the resistivity of compositions containing three magnetic elements will be fully set forth and claimed. To the extent that the subject matter claimed is disclosed in them, this application is a continuation in

part of application, Serial No. 119,623 and also application Serial No. 119,622, filed also on June 30, 1926.

An object of the present invention, therefore, is to increase the resistivity of magnetic materials having other desirable characteristics.

A further object is to reduce eddy current losses in magnetic materials of high initial permeability.

It has been found that by the addition of molybdenum, chromium, tungsten, manganese, vanadium, tantalum, zirconium, copper, and silicon in proper proportions, and with appropriate heat treatments, compositions may be produced which have part or all of the desirable properties of the compositions described and claimed in application Serial No. 119,623 to a greater or lesser extent,—in some instances, to the same extent as, or greater extent than without the added ingredient,—and in addition, a greatly increased resistivity. The production of magnetic compositions of these characteristics which are workable and otherwise suitable for use are of great technical importance.

Although in its preferred form the alloys of the present invention comprise nickel, iron, cobalt and molybdenum (or chromium) properly proportioned and properly heat treated, the nature and proportions of the constituents, especially the nature and proportions of the fourth element, as well as the nature of the heat treatment of the alloy may be modified in order to bring out or lay stress on any particular characteristic.

Manganese may be added in addition to any of the substances mentioned to increase the workability in accordance with known metallurgical practice. Such instances of its use are to be distinguished from those cases in which it constitutes the entire fourth component functioning to increase the resistivity.

It is noteworthy, that chromium, molybdenum, and tungsten, which are among those giving excellent results, are metals of the chromium group of the periodic table. Of the other elements, those which effect the more noteworthy increase of resistivity are closely related, in the periodic table, to chromium. The expression fourth element is spe-

cifically intended to include the general case of two or more elements mixed together and functioning as a fourth element.

Three characteristic heat treatments will now be described. These treatments relate to "pancake" coils of tape material, a few thousandths of an inch thick, a fraction of an inch wide and weighing about 40 grams. The results obtained may vary greatly with variations of heat treatment. In particular certain desirable properties may be accentuated by particular heat treatments.

Treatment I.—In practice this treatment assumed two different aspects, one being characterized by a rather slow rate of cooling, and the other by a relatively fast rate of cooling. The furnace used was an electric resistance furnace capable of having the temperature regulated accurately to any desired value. According to the first aspect, the samples were placed into an annealing pot, heated to 1100° C., maintained at that temperature for one hour and then cooled in the furnace at the following cooling rates: approximately 200° C. per hour for the first hour, approximately 100° C. per hour for the next two hours, approximately 66 $\frac{2}{3}$ ° C. per hour for the next three hours, approximately 50° C. per hour for the next four hours, and approximately 40° C. per hour until approximately room temperature was reached. We shall call this treatment I_a .

According to the second aspect, the samples were placed into an annealing pot and heated to 1100° C., maintained at that temperature for one hour, and then cooled, 100° C. during the first 23 minutes, 200° C. during the next 35 minutes, 200° C. during the next 40 minutes, and 100° C. during each 40 minutes until room temperature was reached. We shall call this treatment I_b .

Treatment II.—This is a so-called double treatment, the first phase of the operation being substantially the same as Treatment I, namely, the samples are annealed at 1100° C., maintained at that temperature for one hour and then cooled in the furnace as specified for treatment either I_a or I_b . This treatment is followed by a second heat treatment consisting in placing the samples in a furnace having a temperature of about 600° C., keeping them there for 15 minutes, then taking them out and cooling them from 600° to 400° C., in such a fashion as to result in an average cooling rate of 1.9° C. per second. No distinction is made as to whether the first part of this treatment was in accordance with I_a or I_b as the results would differ only quantitatively.

Treatment III.—This is a modification of Treatment II, characterized by a cooling rate, after reheating, of 9.5° C. per second from 600° to 400° C. instead of 1.9° C.

The properties which may be imparted to representative compositions of alloys and the methods by which this is done are described

herein with reference to the accompanying drawings. Legends on these drawings and numerical values given in the text relative to magnetizing forces, coercive forces and flux densities are given in c. g. s. units; hysteresis losses in ergs per cubic centimeter per cycle; and resistivities in microhm-centimeters.

Figs. 1 and 2 show two magnetization curves, and two permeability curves of a virgin alloy containing nickel, cobalt, iron and molybdenum, designed to graphically indicate differences in magnetic properties which may be produced by different heat treatments;

Figs. 3 to 11, inclusive, depict the variation of permeability with varying magnetizing force for a number of different alloys;

Figs. 12 to 22, inclusive, represent typical hysteresis loops at various values of maximum induction for typical alloys in accordance with the invention;

Fig. 23 shows graphically the variation of resistivity of an alloy of 45% nickel and 25% cobalt, and the balance iron plus molybdenum, as the molybdenum content is varied from zero to 9%.

Fig. 24 illustrates the variation in permeability for a small alternating magnetizing force upon which is superposed a steady magnetizing force, the amount of which is varied, for an alloy containing approximately 50% Ni, 25% Co, 3.5% Mo, and the balance iron.

Fig. 25 illustrates graphically the magnetizing forces required to cause the permeability to change 1% from the initial value as a function of the molybdenum content.

Fig. 26 depicts graphs representing the initial permeability as a function of the molybdenum content according to various heat treatments;

Fig. 27 shows the percentage by which the permeability departs from the initial value at the flux density of 100 gauss, as a function of the molybdenum content.

Fig. 28 represents the induction at which the permeability departs 1% from the initial value as a function of the molybdenum content.

Fig. 29 shows a graph of the magnetizing forces required to cause the initial permeability to change 1% from its initial value as a function of the chromium content.

Fig. 30 shows a signaling conductor continuously loaded with a magnetic material in accordance with this invention.

The curve A of Fig. 1 represents the relation between magnetizing force H and the induced flux density B in c. g. s. units for a virgin material containing 45.28% Ni, 21.92% Fe, 24.72% Co, 7.16% Mo, .39% Mn and .47% Si. This composition had the high resistivity of 82. It was given heat treatment I_b . The curve indicates that at a magnetizing force of about 10 gauss the induction B is 9,500. At 50 gauss $B = 10,250$. This compo-

sition has been found to possess excellent properties.

Curve B of Fig. 1 shows a magnetization curve for the same composition as that of curve A, but having received a different heat treatment. After the pot annealing at 1100° C. for one hour, this material was cooled in the furnace to room temperature, then it was reheated to about 400° C and this temperature maintained constant for a period of 55 hours; after this the samples were slowly cooled to room temperature. It is easily appreciated from the inspection of the magnetizing curve B that the magnetic characteristics of the alloy were profoundly affected by this different heat treatment.

However, the effects of this prolonged heating are more strikingly brought out by a comparison of the $H-\mu$ curves illustrated in Fig. 2. Curve A of Fig. 2 represents the permeability variation curve of this alloy after treatment I_b. Curve B represents the permeability variation after the prolonged heat treatment. As is easily seen, where there is no exceptionally noteworthy constancy of permeability indicated in curve A, curve B indicates a permeability decidedly constant up to a magnetizing force of 6. This constancy of permeability, however, is accompanied by considerably diminished initial and maximum permeabilities. Whereas the initial permeability of the samples given treatment I_b was 1358, it was only 575 after the prolonged treatment. This decrease in initial permeability does not only occur after such prolonged treatments, but is characteristic of any annealing operation at moderate temperatures of about or more than one hour's duration, whenever the compositions contain cobalt, nickel, iron and molybdenum in the proportions outlined hereinafter. It also applies to those including chromium instead of molybdenum. While this decrease in permeability cannot ordinarily be avoided by treatments designed to develop maximum constancy of permeability, it is compensated for by the increased constancy of permeability which is a characteristic feature of this invention. For particular purposes compositions having sufficiently constant permeability may result from less prolonged annealing at moderate temperatures. It is necessary to strike a balance between the initial permeability and the degree of constancy desired for any particular case.

The magnetizing force at which the permeability changed 1% from the initial permeability was only .017 in the case of heat treatment I_b. It was .61 after the prolonged treatment. Furthermore, the percentage change in permeability, for, $B=100$, was 5.85 in the first case but was only .1 in the second case. The hysteresis loops of specimens of this composition having the heat treatments specified would, for correspond-

ing values of applied magnetizing force, possess similar striking differences in shape and area. The difference in the magnetic properties resulting from different heat treatments are thus strikingly illustrated by this example.

Fig. 3 depicts the variation of permeability with varying magnetizing forces for virgin materials of the following approximate compositions given heat treatment I_a:-

Curve A, 50% Ni, 20% Fe, 25% Co and 5% Mo.

Curve B, 50% Ni, 23% Fe, 25% Co and 2% Mo.

Curve C, 50% Ni, 24% Fe, 25% Co and 1% Mo.

The material represented by curve A had an initial permeability of 568, remaining highly constant up to $H=1.25$; a maximum permeability of 2750 at a magnetizing force of 2.37 gauss; a hysteresis loss of 1060 ergs at a flux density of 5220; a flux density of 11,150 at a magnetizing force of 50 gauss; a remanence of 4020, a coercive force of .84 c. g. s. units; a resistivity of 65.5 microhm centimeters; 1% change in permeability at a magnetizing force of 1.13; and a change in permeability for a flux density of 100 gauss of 0.16%. When this composition was given heat Treatment II, the initial permeability was 1628, whereas Treatment III gave an initial permeability of 1849.

The material whose permeability variation is represented by curve B exhibited an initial permeability of 379 which remained constant up to a magnetizing force of almost 2.3 gauss. The maximum permeability of this composition was about 2000 corresponding to a magnetizing force of 3.45 gauss. Its hysteresis loss at an induction of 6780 was about 2010 ergs per cubic centimeter per cycle, whereas its flux density at a magnetizing force of 50 gauss was 12,900. It had a remanence of 7,700, a coercive force of 1.35, a resistivity of 41.55, a magnetizing force for 1% change in permeability of 2.30 and a percentage change in permeability for a flux density of 100 of 0.078.

Curve C of Fig. 3 represents a variation of permeability of a material whose initial permeability was 317. This material exhibited a maximum permeability of 1810 at $H=4$, a hysteresis loss of 1352 ergs per cubic centimeter per cycle at $B=5725$, a flux density of 13,625 gauss at $H=50$, a remanence of 2681, a coercive force of 1.22, a resistivity of about 31, an H for 1% change in permeability of 1.26, and a percentage change in permeability for $B=100$ of 0.11.

Curve A of Fig. 4 represents the variation of permeability of a virgin material containing approximately 45% Ni, 27% Fe, 25% Co, 2½% Mo and 0.35% Mn, after having been given heat Treatment I_b. The initial permeability of this material was 534 and

was constant to about $H=1.25$. The resistivity was 45.43.

Curve B of Fig. 4 depicts the variation of permeability of a virgin material containing approximately 45% Ni, 29% Fe, 24½% Co, 1% Mo, and 0.20% Mn given heat treatment I_b. The initial permeability of this material was 490 and the permeability was fairly constant up to about $H=1.75$. The resistivity was about 32.

Curve A of Fig. 5 represents the permeability variation of a virgin alloy containing approximately 50% Ni, 21% Fe, 25% Co, 3.50% Mo, and 0.29% Mn, given heat treatment I_b. This material had an initial permeability of 534, which permeability is shown to remain constant up to $H=2$. The resistivity was 53.7. After this material had received heat Treatment II, it exhibited an initial permeability of 1061 and after it had received Treatment III an initial permeability of 1303.

Curve B of Fig. 5 represents the variation of permeability of a virgin alloy containing approximately 30% Ni, 16% Fe, 50% Co, 3.50% Mo, and Mn trace, given heat treatment I_a. The constancy of permeability extended to magnetizing forces up to about 4 gauss. The initial permeability of this alloy was 113. The resistivity was about 47.6.

Curve A of Fig. 6 represents the variation in permeability of a virgin alloy containing approximately 45% Ni, 25% Fe, 25% Co and 4.86% Cu, given heat treatment I_b. It had an initial permeability of 275, a maximum permeability of 1525, at $H=5$; a hysteresis loss of 2010 at $B=5650$; B at $H=50$ of 13,900; a remanence of 2618; a coercive force of 1.494; a resistivity of 18.21; 1% change in permeability at $H=3.1$; and a percentage change in permeability for $B=100$ of 0.02. As compared with the alloys including molybdenum the increased resistivity secured by adding copper is not noteworthy.

Virgin compositions of approximately 50% Ni; 20% Fe; 25% Co, and 5% Cu and 45% Ni, 20% Fe, 25% Co, and 10% Cu exhibited properties not greatly different from that of 45% Ni, 25% Fe, 25% Co and 4.86% Cu.

Curve B of Fig. 6 illustrates the permeability variation of a virgin composition containing approximately 45% Ni, 28% Fe, 25% Co and 1.13% Cr, given treatment I_b. The initial permeability was 475. The resistivity was 32.4.

Curve A of Fig. 7 represents the variation of permeability of a virgin alloy containing approximately 51% Ni, 21% Fe, 24% Co, 3% Cr and about .40% Mn, given treatment I_a. This material had an initial permeability of 451 and a resistivity of 43.0. Heat Treatment II increased the initial permeability to 941 and the heat Treatment III resulted in an initial permeability of 825.

Curve B of Fig. 7 represents the perme-

ability variation of a virgin alloy containing approximately 45% Ni, 27½% Fe, 25% Co, and 2% Cr, given treatment I_b. The curve indicates that the permeability remained practically constant up to $H=$ about 1.7. This alloy had an initial permeability of 509; a maximum permeability of 2350 at $H=3.10$; a hysteresis loss at 1120 at $B=5100$; B at $H=50$ of 13,400; a remanence of 3460; a coercive force of 1.08; a resistivity of 44.25; an H for 1% change in permeability of 1.75; and a percentage change in permeability for $B=100$ of .075. Heat Treatment II produced an initial permeability of 849 and Treatment III gave an initial permeability of 1077.

A virgin alloy containing approximately 45% Ni, 27% Fe, 25% Co, 3% Cr and 0.33% Mn, exhibited an initial permeability of about 500, a constancy of permeability up to $H=1.10$, a maximum permeability of about 110 after heat treatment I_b. The increase in permeability between $H=1.4$ and $H=2.1$ was striking.

Fig. 8 represents the permeability of a virgin alloy containing approximately 45% Ni, 27% Fe, 25% Co, 3% W and 3% Mn after having been given heat treatment I_b. The curve indicates that the permeability remained constant up to $H=$ about 1.6. This alloy had an initial permeability of 510; a resistivity of about 34.3 an H for 1% change in permeability of 1.6; and a percentage change in permeability for $B=100$ of .04. After Treatment II the initial permeability was 816 and after Treatment III the initial permeability was 931.

Curve A of Fig. 9 is representative of the permeability variation of a virgin alloy containing approximately 46% Ni, 27% Fe, 24% Co, and 2.85% Mn after treatment I_b. This composition exhibited an initial permeability of 435, and a resistivity of about 30; after Treatment II the initial permeability was 866; after Treatment III the initial permeability was 1260.

Curve B of Fig. 9 depicts the permeability variation of a virgin material containing approximately 45% Ni, 27% Fe, 25% Co, and 3% Va when given heat treatment I_a. This alloy had an initial permeability of 340, which remained constant for $H=$ about 1.2. The hysteresis loss was only 968 for $B=5100$. The resistivity was about 42.6; H for 1% change in permeability was about 1.2; and the percentage change in permeability for $B=100$ was .75. Heat Treatment II gave an initial permeability of 602 and heat Treatment III gave an initial permeability of 1143.

A virgin composition containing approximately 44% Ni, 29% Fe, 25% Co, 1% Si, and .56% Mn, exhibited an initial permeability of 347; a maximum permeability of 2120 at $H=3.15$; a very low hysteresis loss of 625 for $B=4850$; a B at $H=50$ of 14,000;

a remanence of 2118; a coercive force of .67; a resistivity of 28.22; an H for 1% change in permeability of 1.05; and a percentage change in permeability for B=100 of .18 after heat treatment I_a. Heat Treatment II resulted in an initial permeability of 852 and heat Treatment III in an initial permeability of 1085.

The curve of Fig. 10 shows the permeability variation of a virgin alloy containing approximately 44 1/2% Ni, 27% Fe, 25% Co, 2.86% tantalum and .59% Mn, when given heat treatment I_b. This composition had an initial permeability of 347. The change in permeability at H=.9 was about 1%, but the increase in permeability was very little up to H=3. The resistivity was about 30.

Fig. 11 represents the permeability vs. magnetizing force curve of an alloy containing approximately 45% Ni, 25% Co, 27% Fe and 3% zirconium. This material was given heat treatment I_a. It had a remanence of 2550; a coercivity of 1.29; and a resistivity of 37. The permeability varied slightly over the range H=0 to H=1.25 but this variation was inconsiderable. A striking feature is the relatively small ratio of the initial to the maximum permeability.

The curves given above relate to virgin materials. In practice, however, the behavior of such compositions under varying magnetizing forces is of prime importance. In general these and other compositions of similar characteristics, when properly heat treated have the following characteristics:—

1. Constant or very nearly constant permeability over a considerable range of flux densities from zero upward.

2. Substantial absence of hysteresis over a considerable range of flux densities from zero upward.

3. Relatively high initial permeability and high permeability at magnetizing forces within the range of flux densities utilized in magnetic materials for telephone, telegraph and cable circuits and apparatus.

4. At high flux densities the hysteresis loss, remanence, and coercive force are low.

5. At flux densities above that at which the hysteresis is entirely or almost negligible, the hysteresis loop widens out and assumes a peculiar form characterized by a constriction at the origin.

6. The resistivity is high, values up to 80 are readily secured with little or no attendant impairment of other desirable properties. This is particularly true with those compositions including molybdenum.

Typical examples of hysteresis loops will now be discussed to illustrate graphically the properties (2) and (5) mentioned above.

Fig. 12 illustrates the hysteresis loops of a composition of approximately 45% Ni, 26% Fe, 25% Co, 4% Mo and 2% Mn after

being given heat treatment I_b. For magnetizing forces up to 1.57 the loop was a straight line A and no hysteresis could be detected by ordinary methods. At a maximum magnetizing force of H=2 the curve B resulted; the hysteresis loss was 232 ergs per cu. cm. per cycle. At H=2.14 the curve C resulted and the loss was 929 ergs.

Figs. 13, 14 and 15 show hysteresis loops of a composition of approximately 45% Ni, 27% Fe, 25% Co, 3% Cr and 1/3% Mn after heat treatment I_b. The hysteresis loop of Fig. 13 was a straight line up to H=.6; at H=1.38 (Fig. 14) the hysteresis loss was 7.6 ergs per cu. cm. per cycle; at H=1.63 (Fig. 15), the loss was 132 ergs; and at H=1.9 (Fig. 16) the loss was 924 ergs.

Figs. 17, 18 and 19 show hysteresis loops of a composition of approximately 46% Ni, 27% Fe, 24% Co, and 2.85% Mn. This is the same composition and heat treated in the same manner as that to which curve A of Fig. 9 relates.

The hysteresis loops are as follows:

Maximum magnetizing force	Figure	Curve	Hysteresis loss in ergs per cu. cm. per cycle
0.64	17	A	0
1.25	17	B	Negligible
1.83	18		87
2.6	19		834

It is noteworthy that both branches of the curve of Fig. 19 pass through the origin. This indicates that the remanence and coercive force after an applied magnetizing force of 2.6 are both negligibly different from zero.

Figs. 20, 21 and 22 show hysteresis loops for the composition to which the curve A of Fig. 6 relates. The heat treatment was the same.

Maximum magnetizing force	Curve	Hysteresis loss in ergs per cu. cm. per cycle
3.4	20	20
3.8	21	183
4.3	22	2010

The remanence and coercivity, after an applied magnetizing force of 4.3 gauss, were very small.

Fig. 23 shows the variation of the resistivity in microhms per cu. cm. of various compositions of 45% Ni, 25% Co, and 30% (Fe+Mo) as progressively increasing amounts of iron are replaced by molybde-

num, as a function of the molybdenum content. The resistivity increases markedly with increasing molybdenum content from about 20 at zero molybdenum up to about 88 microhms per cu. cm. when the molybdenum content reaches 9%.

Fig. 24 illustrates graphically the relation of the permeability to an alternating current magnetizing force of about .00679 gauss and suitable frequency, for example 200 cycles per second, when a steady magnetizing force is superposed on the magnetic circuit, the steady force being produced by a direct current increased in small steps. The specific material to which this curve relates contained 50% nickel, 25% cobalt, 21.5% iron and 3.5% molybdenum. It was given heat treatment I_b . The arrows in this figure indicate the direction of the variation of the permeability as the direct current magnetizing force is varied. Only one half of the complete curve is shown, the gradual application and removal of magnetizing forces in the opposite sense causing the graph to substantially repeat itself at the left of the coordinate. Another characteristic of this material which is not found in ordinary magnetic materials is a higher permeability at low magnetizing forces after a direct current magnetizing force of large value has been removed from the magnetic circuit. In the case of Fig. 17 the permeability has increased from approximately 440 to 760.

Fig. 25 illustrates graphically the magnetizing forces required to cause the permeability to change 1% from its initial value as a function of the molybdenum content in a composition of 45 Ni, 25 Co and 30% (Fe+Mo) after heat treatment I_a . With increasing molybdenum content the magnetizing force required to bring about 1% change in permeability has a high value up to about 4% molybdenum.

Fig. 26 represents the initial permeability as a function of the molybdenum content according to various heat treatments. The alloys considered are approximately 45% nickel, 25% cobalt, and 30% (Fe+Mo). Curve III shows that heat Treatment III is conducive of the development of the highest initial permeability which reaches a peak value of about 2500 at about 4% molybdenum content. Heat Treatment II (Curve II) develops, in general, a lower initial permeability which reaches a peak value of about 2000 at a molybdenum content of about 5.50%. Heat treatment I_b (curve I_b) results in still lower initial permeabilities, the maximum occurring at a molybdenum content of about 7%. Heat treatment I_a (curve I_a) has a similar effect although the initial permeabilities are lower.

Tests on the same series of compositions (heat treatment I_a) at magnetizing forces of 50 c. g. s. units show that the flux density

varies linearly from 15,000 gauss at 0% molybdenum to about 9,700 gauss at 8% molybdenum.

The percentage by which the permeability departs from the initial value at a flux density of $B=100$ is illustrated in Fig. 27 as a function of the molybdenum content for alloys containing approximately 45% nickel, 25% cobalt, and 30% (Fe+Mo). Heat treatment I_b is used. With increasing molybdenum content the percentage of departure increases slightly up to a molybdenum content of about 5.50%. With heat treatment I_a the increase is slight up to a somewhat higher molybdenum content.

The induction at which the permeability departs 1% from the initial value is illustrated in Fig. 28 for various alloys of the same composition as those of Fig. 19, as a function of their molybdenum content. This reaches a maximum of about 1100 at a molybdenum content of around 4% and then very rapidly decreases to a low value at a molybdenum content of 7%.

Fig. 29 shows the magnetizing forces required to cause the initial permeability to change 1% from its initial value for a composition of 45% nickel, 25% cobalt, 30% (Fe+Cr), when given heat treatment I_b .

With the same series of compositions the flux density at which the permeability changes 1% from its initial value is high up to about 2% chromium, and falls to lower values for greater percentages of chromium. It is about 870 at 2% chromium.

The resistivity varies from 20 at 0% chromium to about 58 at 6% chromium.

With heat treatment III the initial permeability will be above 800 for all chromium contents up to 6%. Between 3% and 6% chromium values of permeability of 1600 are readily obtained. With heat Treatment II the initial permeability is about 800 at 0% chromium and increases to about 1550 at 6% chromium. With heat treatment I_b initial values of 400 occur at 0% chromium and increase to about 1200 at 6% chromium. The heat treatments giving the lower initial permeabilities result, in general, in greater constancy.

The examples herein given indicate that suitable compositions of iron, nickel, and cobalt when properly heat treated may, in addition to their other desirable properties, especially constant permeability, and low hysteresis loss, be caused to be of high resistivity. Values of resistivity of at least 80 microhms per cu. cm. are attainable. Experiments to date indicate that the range of possible compositions with properties similar to those of the compositions mentioned but differing in degree is as extensive as the range in which iron, cobalt, and nickel alone possess unusual properties to a greater or lesser extent i. e. 9% to 81% nickel, 5% to

80% cobalt, and 9% to 50% iron, and that other elements or combinations of two or more elements such as molybdenum, chromium, etc., may be added in varying amounts up to 10% or more depending upon the particular element employed.

All of the compositions specifically set forth in this specification have been found to be workable by methods usually employed.

The highest initial permeability with compositions including molybdenum and chromium generally results with heat Treatment III. Greater constancy of permeability is generally secured by heat treatment I_a.

A general rule is that slower cooling and prolonged maintenance at moderate temperatures (400° to 500° C.) gives decreased initial, but much more constant, permeability. A heat treatment, in any particular case, will be determined by the magnetic properties desired in a particular composition as well as by economic factors.

Certain compositions which are less noteworthy for their constancy of permeability have other exceptional properties. Thus a composition of 45% Ni, 20% Fe, 25% Co, 9.1% Mo, .05% Mn, 7% Si was easily produced with an initial permeability around 1000. The resistivity was 88. These two properties in combination are noteworthy. Compositions including around 6% chromium may be produced with a resistivity of 60 and an initial permeability of over 1500.

The relative values of the several compositions are dependent upon a number of considerations. Copper, although it increases the resistivity but little, or possibly none in some cases, may have other worth while advantages in these particular compositions. The strain sensitiveness, tendency to stick to a loaded conductor, and other factors are material to the value of any composition for continuous loading purposes.

One important application of the compositions described herein is their use as loading material for continuously loaded signaling conductors such as submarine telegraph or telephone cables. For this purpose the magnetic material is formed by known methods into a tape of approximately .002" thickness and .020" width and applied helically to a stranded conductor as represented in Fig. 30. In a particular instance, two layers 5 and 6 of the magnetic material discussed in connection with Figs. 1 and 2 were applied to a stranded core consisting of a central solid wire 10 surrounded by a plurality of strands 11 shaped to fit around the central wire. All of these materials are sensitive to mechanical strain and all coiling and uncoiling after heat treatment must be on a large radius. Other usually practiced precautions against strain are to be observed.

When applied to the continuous loading of

conductors the method of heat treating of the magnetic material may be varied. The heat treatments described hereinafter were carried out in an electric resistance furnace. In one instance the composite core was placed in an annealing pot which was slowly heated to about 800° C. and kept at that temperature for about one hour. After this the conductor was allowed to cool to room temperature within the furnace; this ordinarily required about 10 hours. This treatment produces fair values of initial permeability and constancy of permeability.

If, however, the greatest constancy of permeability is desired, the cooling of the conductor should be interrupted at a temperature of 400° to 500° C. this temperature maintained constant for about 8 hours, and the conductor then allowed to cool slowly to room temperature.

If intermediate values of permeability and constancy of permeability are desired, the length of time for which the conductor is maintained at a temperature of 400° to 500° C. is varied to obtain these results.

In another case the composite conductor was passed through an annealing furnace in a continuous process at such a rate as to be annealed at about 800° to 900° C. After cooling the conductor was wound in coils of large radius and again heat treated at about 350° to 450° C., for a length of time required to bring the initial permeability to the required value, followed by slow cooling in the furnace.

In accordance with a modified method, after heating it to about 400° to 450° C., it is cooled at a moderate rate, such as cooling the annealing pot and contents in air.

An annealing pot of large size should be employed so that the conductor may be coiled on a large radius.

Among the uses for which these materials are adapted are coil or lumped loading and continuous loading of carrier frequency signaling conductors in submarine and land line telegraphy and telephony, loading coils for composite telephone and telegraph systems, repeating coils or transformers, especially battery supply coils, wave filter coils, certain classes of relays, high frequency electromagnetic devices and magnetic circuits of electrical measuring instruments.

The several alloys herein described and others of similar characteristics may be employed in laminated form or reduced to powder and compressed into cores with suitable binders or insulating materials, separating the particles in accordance with methods proposed and employed for permalloy dust cores.

What is claimed is:

1. A magnetic material including as essential elements iron, nickel, and cobalt, characterized by a high degree of constancy of

- permeability over a range of magnetizing forces including the range employed in continuous loading of electrical signaling conductors, and including additional material to increase the resistivity, said additional material being selected to include at least one of the following elements: molybdenum, chromium, tungsten, manganese, vanadium, tantalum, zirconium, copper and silicon.
2. A composition in accordance with claim 1 characterized by a nickel content of 9% to 81%, cobalt 5% to 80%, iron 9% to 50% of the nickel-cobalt-iron content and additional material up to about 10% of the entire composition.
3. A composition in accordance with claim 1 characterized in that the additional material comprises from $\frac{1}{2}\%$ to 10% of metal of the group of elements comprising chromium, molybdenum and tungsten.
4. Magnetic alloy having small variation in permeability over at least that range of magnetizing forces employed in continuous loading of electrical signaling conductors, containing nickel, iron, cobalt and a fourth element for increasing the resistivity thereof.
5. Magnetic alloy having negligible variation in permeability over a range of magnetizing forces including the range employed in continuous loading of electrical signaling conductors, containing nickel, iron, cobalt and a metal of the group of elements including chromium, molybdenum and tungsten.
6. Magnetic alloy in accordance with claim 4 heat treated to have initial permeability higher than that of soft iron.
7. Magnetic alloy in accordance with claim 4 characterized by a resistivity of over 20 microhms per cubic centimeter.
8. Magnetic alloy in accordance with claim 4 characterized by a permeability varying less than 1% up to magnetizing forces of .20 gauss.
9. Magnetic material having negligible variation of permeability over a substantial range of magnetizing forces comprising cobalt, nickel and iron and having its resistivity increased by the addition of molybdenum.
10. Magnetic alloy in accordance with claim 4 containing nickel, iron, cobalt and molybdenum in such proportion as to impart a higher resistivity than is possessed by a similar alloy with the molybdenum replaced by iron.
11. Magnetic alloy including nickel, cobalt and iron characterized by constancy of permeability over a range of magnetizing forces, having a molybdenum content of from 1% to 8% of the total.
12. A magnetic material including nickel between 9% and 81%, cobalt between 5% and 80%, iron between 9% and 50% of the nickel-cobalt-iron content, with a content of metal of the group of elements including chromium, molybdenum and tungsten between 1% and 8%, characterized by high constancy of permeability and low hysteresis loss in a wide range of magnetizing forces including the range employed in continuous loading of signaling conductors.
13. A magnetic material in accordance with claim 12, in which the nickel content is between 30% and 60%, cobalt 10% to 50% and iron between 10% and 40% of the nickel-cobalt-iron content.
14. A magnetic material containing approximately 45% nickel, 25% cobalt, a molybdenum content of zero to 10% and the balance iron.
15. A magnetic composition including 40% to 50% nickel, 20% to 30% cobalt, 22% to 25% iron and 3% to 8% molybdenum.
16. The method of developing high initial permeability in a magnetic composition including iron, nickel and cobalt, comprising heating said material to a temperature between 1,000° and 1,150° C. for at least one hour, cooling said material to below 400° C. within the furnace at an average rate of 1/2° to 5° C. per minute, reheating said material to between 400° and 600° C., and cooling it at an average rate between 5° and 25° C. per second.
17. The method of developing high constancy of permeability in a magnetic material containing nickel, cobalt and iron which comprises heating it to a temperature of about 1100° C. for at least one hour and cooling it at a rate not exceeding 200° C. per hour, and through the range 600° to 400° C. at less than 100° C. per hour.
18. The method of developing a high degree of constancy of permeability in a magnetic composition containing nickel, iron and cobalt as essential elements, which includes first heating it to a temperature above 800° C. for about one hour and subsequently maintaining it within the range of 400° to 600° C. for a plurality of hours sufficient to produce the desired constancy of permeability, and then slowly cooling the material.
19. A transmission conductor loaded with a magnetic material comprising nickel more than 9%, cobalt more than 5%, iron more than 9% and a fourth element for increasing the resistivity, characterized by a substantially constant permeability for magnetizing forces up to at least .2 gauss.
20. A magnetic material including nickel between 9% and 81%, cobalt between 5% and 80%, iron between 9% and 50% of the entire nickel-cobalt-iron content and heat treated to have desirable magnetic properties at small magnetizing forces characterized further by the inclusion of a material amount but less than 10% of material selected to include at least one of the following elements: molybdenum, chromium, tungsten, manganese,

vanadium, tantalum, zirconium, copper and silicon. small magnetizing forces and including a substantial quantity but less than 10% of

21. A magnetic material including nickel molybdenum. 10
between 9% and 81%, cobalt between 5% In witness whereof, I hereunto subscribe
5 and 80%, iron between 9% and 50% of the my name this 17th day of September, A. D.
entire nickel-iron-cobalt content, heat treated 1927.
to have desirable magnetic properties at

GUSTAF W. ELMEN.