Dec. 18, 1951 H. W. LEVERENZ ET AL 2,579,267

MATERIAL HAVING IMPROVED MAGNETIC PROPERTY

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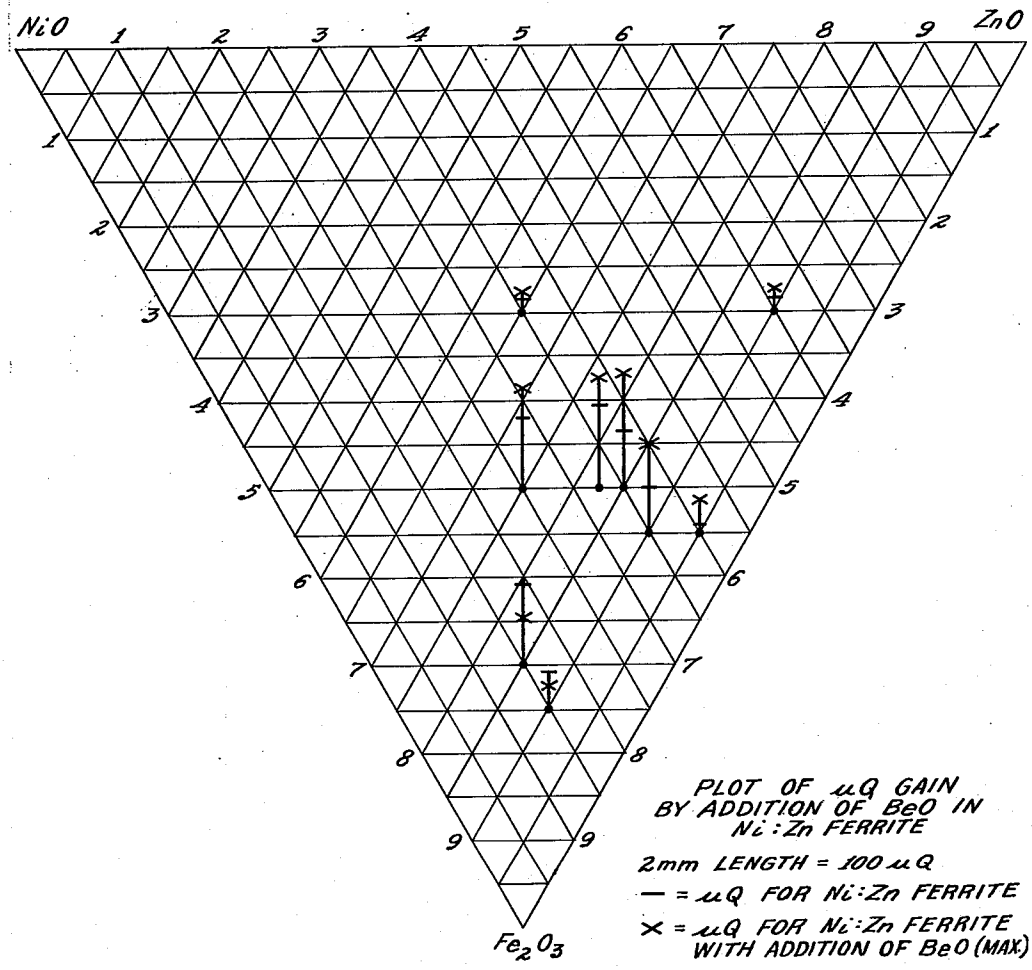

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MATERIAL HAVING IMPROVED MAGNETIC PROPERTY

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This invention relates to materials having improved magnetic properties. These materials may have unusually high values of magnetic permeability, or they may have desirably low loss values (high Q factors) at radio frequencies, or a usefully high product of these two values. They may also have desirable properties of magnetostriction and good stability at operating temperatures. They may also have an improved modulus of elasticity and good resistivity.

Wherever Q values are discussed or stated throughout this specification, there is meant a numerical value found by dividing the radio frequency reactance by the resistance of a circuit in which the materials of the present invention are introduced as induction coil core bodies.

More particularly, the present invention relates to materials known as ferrites, made by the general method described in co-pending application of H. W. Leverenz and R. L. Harvey entitled "Improvement in Magnetic Materials," Serial No. 776,292, filed September 26, 1947, now Patent No. 2,565,861.

The present improvement is especially related to the use of beryllium oxide, BeO, either substituted for part of the oxides previously disclosed, in the said application or elsewhere in the prior art, or in addition to the materials therein mentioned.

One object of the present invention is to provide compositions having improved magnetic properties.

Another object of the invention is to provide materials having controllable and unusually high values of magnetic permeability.

Another object of the invention is to provide materials having low loss values (high Q factors).

Another object of the invention is to provide materials having improved magnetic properties and also high Curie temperatures.

Another object of the invention is to provide materials having a desirably wide range of magnetostriction.

Another object of the invention is to provide materials having improved magnetic properties along with a desirable modulus of elasticity.

Another object is to provide improved compositions of magnetically permeable ferrites which include beryllium oxide as an essential ingredient.

Still another object is to provide materials having desirable values of resistivity.

These and other objects will be more readily apparent and the invention will be better understood with reference to the following specification, including the drawing, of which the single figure is a graphical representation of the improvement in the product μQ obtained by addition of BeO in a Ni-Zn ferrite.

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Although the compositions, which are a part of the present invention, are different from those described in the previously mentioned co-pending application, Serial No. 776,292, the general method of preparation is the same as illustrated therein. Briefly, this method includes the intimate mixing of ferric oxied and the various other oxides involved, each in a fine state of subdivision, heating, preferably, a compressed body made of these oxides within a range of temperatures of about 900° C. to about 1500° C. for about 1 minute to about 5 hours in an oxidizing atmosphere, and then cooling. Longer heating times are required for larger bodies. Optimum conditions of time and temperature of heating will vary with each specific composition possible within the systems of compositions which are a part of the present invention and, with any specific composition, the optimum heating time decreases as the temperature of heating increases. In general, however, some improvement in results is obtained by selecting widely varying times and temperatures within the ranges specified, even though these improvements will not be the maximum obtainable when a more careful choice is made. Good results can be expected with almost any of the compositions, if a heating time of about 1 hour is used, and a heating temperature of the order of 1200° C. has proved satisfactory, if not always best, with all of the compositions. The reaction product which is fromed in all instances is a composite, homogeneous, crystalline body wihch does not have the same stoichiometric proportion of oxygen to metals as is present in the mixture before heating, but the exact proportions of the elements present in the products is not known and cannot easily be determined.

The oxidizing atmosphere in which the heating of the reaction mixture takes place may be supplied by passing a stream of oxygen through the reaction chamber. Less desirably, air may be used in place of oxygen. It is also possible to form products having improved magnetic permeability and low loss by heating the oxides in a neutral atmosphere, such as one comprising helium or nitrogen, but the improvement is not as great as when an oxidizing atmosphere is used. In contrast to the use of either an oxidizing or a neutral atmosphere, the presence of a reducing atmosphere, such as supplied by carbon monoxide or hydrogen, in the reaction chamber, is distinctly detrimental, if materials having high permeability are desired. Therefore, it may be said that the heating should take place in a non-reducing atmosphere, preferably at atmospheric or higher pressures.

Instead of starting with the oxides themselves, it is possible to start wwith a mixture of mate-

rials in other than the oxide form in which they are present in the reaction product, provided these starting materials will be changed to the specified oxide upon heating to the temperatures, times and atmospheric conditions stipulated. For example, instead of starting with a mixture containing Fe_2O_3, the iron may be in the form of ferrous oxide or magnetite, providing that heating takes place in an oxidizing atmosphere, and as the hydroxide, carbonate, etc., if either an oxidizing or a neutral atmosphere is present. The other ingredients may also be present in forms such as hydroxides, acetates or carbonates or either lower or higher oxide forms than are present in the final product, since these will revert to the desired oxide form when heated strongly in the preferred oxidizing atmosphere and, in some cases, even in a neutral atmosphere. Certain of the present compositions also utilize oxides of manganese. This is preferably present as MnO_2 in the initial mixture but changes to MnO in the reaction product. This change occurs even though an oxidizing atmosphere be used, providing the oxidization properties of the atmosphere are not strong enough to prevent the reduction of the higher valent oxide to the lower divalent form. Likewise, other oxides of manganese can be used in the starting mixture since these will revert to MnO when heated in the oxidizing atmosphere. Similarly, it is possible to use oxide of copper or nickel since there also will change to the desired form when heated under the oxidizing conditions preferred.

Because of the brittleness of the reaction products, compressed bodies of the reactants may be formed at pressures of, say, 20,000 pounds per square inch and these compressed bodies are treated at elevated temperatures in order to impart the desired properties of increased permeability, low loss, etc., desired in the end product. These compressed bodies may also be formed by extrusion molding processes at much lower pressures. The fact that shaped bodies of the compressed material can be formed without the presence of a permanent binder adds much to their improvement over materials previously known, such as powdered iron, which requires the use of a permanent binder, since the binder introduces a multitude of gaps of considerable size between the particles, and the gaps, themselves, are responsible for much of the lower permeability hitherto present in materials of this nature. When the material is made in the form of compressed bodies, the pressure of forming may vary widely. Pressures of 2,000 pounds per square inch have been found to produce the same improved results as those ten times as great and extrusion molding techniques have been used with excellent results. For example, the ingredient oxides may be pre-heated, mixed with a temporary binder and extrusion molded and heat treated. In general, it may be said that the pressure of forming should be sufficient to form a closely coherent body and the pressures used should simply be those necessary to obtain this result.

After the heat treatment has been accomplished as described, the reaction product is preferably, although not necessarily, cooled very rapidly, as by subjecting it to a blast of air or quenching in water. Rapid cooling generally increases the permeability and low loss qualities above those values obtained when slow cooling is used.

The reaction mixture may be compressed into any desired shape before heating takes place in the reaction chamber. The danger of warping of the compressed bodies, when heated, may be lessened by mixing a small percentage of a lubricant with powdered oxides before compression. The preferred lubricants are those which are completely burned off during the heat treatment process. Suitable examples are stearic acid and microcrystalline waxes, such as Carbowax.

Other improvements in molding technique are described in the previously mentioned co-pending application, such as releasing pressure uniformly from the mold piston after compressing the oxide mixture into the desired shape.

As previously stated, the present invention relates more specifically to the use of beryllium oxide in ferrite bodies, prepared as described. In a wide range of compositions, it has been found that the addition of beryllium oxide produces desirable improvements not obtainable when mixtures of oxides, not including beryllium oxide, are used.

One of the new systems, according to the present invention, is a quaternary system comprising BeO, MnO, ZnO and Fe_2O_3. In Table I below are given examples of various compositions of these four ingredients expressed in mole parts. First, there is given a composition with the beryllium oxide omitted and this is followed by compositions in which various small proportions of beryllium oxide have been substituted for part of the zinc oxide, with the proportions of the other two ingredients remaining constant for purposes of comparison. In each case, in all of the tables which follow, the values of several magnetic properties are given: i. e., effective permeability $\mu_{eff.}$, the reciprocal of the loss value Q, the product μQ, and, in a few instances, the Curie temperature. Since the Curie temperature is a temperature at which a marked change of properties occurs, probably due to crystalline reorganization, it is desirable to have the Curie temperature of a composition as far above operating temperatures as is convenient since, if the Curie temperature falls within the range of operating temperatures, the magnetic properties may vary quite widely when the material is in use. The values in Table I were obtained by crystallizing the materials at 1200° in an oxygen atmosphere.

Table I

BeO	ZnO	MnO_2	Fe_2O_3	$\mu_{eff.}$	Q	μQ	Curie Temp.
							° C.
0	0.25	0.25	0.5	15.9	40	636	115
0.025	0.225	0.25	0.5	16.0	55	880	124
0.075	0.175	0.25	0.5	14.6	105	1533	200
0.125	0.125	0.25	0.5	12.8	117	1498	

In the above system, is has been found that the physical nature (e. g., density, particle size, degree of aggregation) of the manganese dioxide influences the maximum μ and Q and the rate of attainment of the maximum μ and Q. Dense particles of moderate size, such as 1 to 10 microns, are preferable to very small particles (e. g., less than 0.1 micron). The degree of purity of the MnO_2 and other ingredients is also an important factor, high purity being desirable. During the crystallization process, brought about by the heat treatment, the MnO_2 decomposes to afford MnO.

BeO was also substituted for part of the MnO_2 in preparing materials falling within the $BeO:ZnO:MnO:Fe_2O_3$ system with results shown by the examples listed in Table IA. It will be seen that here, also, the use of BeO resulted in com-

positions having improved magnetic properties. Crystallization was carried out at 1200° C. in oxygen.

Table IA

BeO	ZnO	MnO_2	Fe_2O_3	$\mu_{eff.}$	Q	μQ
0	0.25	0.25	0.5	15.5	36	558
0.02	0.25	0.23	0.5	15.6	45	702
0.10	0.25	0.15	0.5	14.9	86	1281
0.20	0.25	0.05	0.5	8.8	87	766

Keeping the ZnO and MnO_2 content constant, BeO was also substituted for part of the Fe_2O_3 in preparing materials within the system

$$BeO:ZnO:MnO_2.Fe_2O_3$$

with results illustrated in Table IB. Crystallization was carried out at 1200° C. in oxygen.

Table IB

BeO	ZnO	MnO_2	Fe_2O_3	$\mu_{eff.}$	Q	μQ
0.02	0.75	0.25	0.48	15.8	37	585
0.05	0.25	0.25	0.45	15.2	27	410

Another modification in the method of preparing crystalline materials within the system

$$BeO:ZnO:MnO_2:Fe_2O_3$$

was carried out by adding BeO with molecular proportions of all of the other ingredients remaining constant. Crystallization was carried out at 1200° C. in oxygen. Data are shown in Table IC.

Table IC

BeO	ZnO	MnO_2	Fe_2O_3	$\mu_{eff.}$	Q	μQ
0.01	0.25	0.25	0.5	15.6	45	702
0.04	0.25	0.25	0.5	15.5	44	682
0.06	0.25	0.25	0.5	15.7	46	722
0.20	0.25	0.25	0.5	14.8	65	962

In Table II below, values are given for a crystalline system comprising

$$BeO:ZnO:NiO:Fe_2O_3$$

The values in this table were obtained by crystallization of the materials at 1400° C. in an oxygen atmosphere.

Table II

BeO	ZnO	NiO	Fe_2O_3	$\mu_{eff.}$	Q	μQ	Curie Temp.
							° C.
0	0.35	0.15	0.5	15.2	39	593	80
0.02	0.33	0.15	0.5	15.2	72	1090	130
0.125	0.225	0.15	0.5	14.4	82	1180	276
0.2	0.15	0.15	0.5	8.4	76	638	--
0.3	0.05	0.15	0.5	3.3	102	337	--
0	0.25	0.25	0.5	12.5	54	675	--
0.05	0.2	0.25	0.5	12.2	85	1037	--
0.125	0.125	0.25	0.5	9.2	95	874	--
0	0.325	0.175	0.5	14.9	59	879	--
0.02	0.305	0.175	0.5	14.3	77	1101	--
0.1	0.225	0.175	0.5	12.6	86	1084	--
0	0.35	0.1	0.55	13.3	30	399	--
0.05	0.3	0.1	0.55	13.2	63	832	--
0	0.4	0.05	0.55	2.6	11	29	--
0.05	0.35	0.05	0.55	13.2	31	409	--
0	0.35	0.35	0.3	4.0	38	152	--
0.1	0.25	0.35	0.3	4.1	48	197	--
0	0.6	0.1	0.3	7.3	18	131	--
0.1	0.5	0.1	0.3	6.0	30	180	--
0	0.15	0.15	0.7	7.3	111	810	--
0.025	0.125	0.15	0.7	6.5	77	501	--
0	0.1	0.1	0.8	4.4	83	365	--
0.025	0.075	0.1	0.8	3.5	75	262	--

In the above table, it will be noted that data are given for compositions in which various percentages of ferric oxide are used and also in which the nickel oxide and zinc oxide are varied widely.

In Table III, values are given for a system comprising BeO:ZnO:MgO:Fe_2O_3. These values were obtained by crystallization at 1300° C. in an oxygen atmosphere.

Table III

BeO	ZnO	MgO	Fe_2O_3	$\mu_{eff.}$	Q	μQ	Curie Temp.
							° C.
0	0.25	0.25	0.5	15.1	44	664	115
0.02	0.25	0.25	0.5	13.2	57	752	356
0.1	0.15	0.25	0.5	10.3	65	670	--
0.125	0.125	0.25	0.5	9.2	60	552	--
0.2	0.05	0.25	0.5	4.4	75	330	--
0	0.35	0.15	0.5	1.2	27	32	--
0.05	0.3	0.15	0.5	8.3	30	249	--
0	0.3	0.3	0.4	10.0	23	230	--
0.02	0.28	0.3	0.4	11.8	18	212	--
0.05	0.25	0.3	0.4	9.5	37	352	--
0	0.35	0.35	0.3	5.0	8	40	--
0.05	0.3	0.35	0.3	6.0	22	132	--
0	0.2	0.2	0.6	9.2	70	644	--
0.02	0.18	0.2	0.6	9.7	65	631	--
0.05	0.15	0.2	0.6	8.2	75	615	--
0	0.225	0.225	0.55	12.1	65	786.5	--
0.05	0.175	0.225	0.55	10.5	75	788	--
0	0.3	0.05	0.65	10.9	50	545	--
0.02	0.28	0.05	0.65	8.6	95	817	--

Table IV contains values obtained for a system comprising BeO:ZnO:CuO:Fe_2O_3. The values were measured for materials crystallized at 1200° C. in an oxygen atmosphere.

Table IV

BeO	ZnO	CuO	Fe_2O_3	$\mu_{eff.}$	Q	μQ	Curie Temp.
							° C.
0	0.3	0.2	0.5	14.2	20	284	40
0.02	0.28	0.2	0.5	14.2	30	426	---
0.07	0.23	0.2	0.5	15.2	59	897	130
0.1	0.2	0.2	0.5	14.4	73	1,051	---
0.15	0.15	0.2	0.5	12.5	72	900	---
0	0.35	0.15	0.5	1.04	53	55	---
0.05	0.3	0.15	0.5	4.0	20	80	---
0	0.4	0.1	0.5	1.2	29	35	---
0.02	0.38	0.1	0.5	1.2	35	42	---
0.05	0.35	0.1	0.5	1.02	57	58	---
0	0.35	0.2	0.45	1.06	50	53	---
0.05	0.3	0.2	0.45	1.8	20	36	---
0	0.25	0.2	0.55	15.7	42	659	---
0.05	0.2	0.2	0.55	14.9	60	894	---

Table V contains values for a few examples of compositions within the system

$$BeO:CdO:CuO:Fe_2O_3$$

Crystallization was at 1200° C. in an oxygen atmosphere.

Table V

BeO	CdO	CuO	Fe_2O_3	$\mu_{eff.}$	Q	μQ
	0.30	0.20	0.50	13.6	20	272
0.02	0.28	0.20	0.50	14.0	25	350
0.05	0.25	0.20	0.50	14.2	35	497
0.10	0.15	0.20	0.50	12.0	71	852

It will be noted that for small additions of BeO to replace some of the CdO, the permeability rises and so does the Q value. When the amount of BeO is increased, the permeability drops but the Q value rises so rapidly that the μQ product is greatly improved.

Table VI contains examples within the system BeO:CdO:MnO:Fe_2O_3. Crystallization was at 1200° C. in an oxygen atmosphere.

Table VI

BeO	CdO	MnO^2	Fe_2O_3	$\mu_{eff.}$	Q	μQ
0.10	0.25	0.25	0.50	15.6	26	406
0.05	0.20	0.25	0.50	13.7	60	822
0.10	0.15	0.25	0.50	10.6	65	689

In these compositions, marked improvement in Q value is evidenced when BeO is added to the basic ternary system.

Table VII shows the effects of adding BeO to the system $MnO:ZnO:CdO:Fe_2O_3$ to form a pentanary system including BeO. The Q value of the materials is raised considerably. Crystallization was at 1200° C. in an oxygen atmosphere.

Table VII

BeO	ZnO	CdO	MnO_2	Fe_2O_3	$\mu_{eff.}$	Q	μQ
0	0.125	0.125	0.25	0.5	15.4	29	447
0.05	0.10	0.10	0.25	0.5	14.3	72	1030

In all of the above systems, the beryllium oxide was added to the mixture before the mixture was compressed and crystallization carried out. In general, it has been found that the addition of about 0.2 to about 30 mole percent of co-crystallized BeO improves the product μQ ("figure of merit") of the ferrite solid, and somewhat higher values (e. g., up to about 50 mole-percent BeO) may be used to obtain improved Q values, although the product μQ may not be improved when the highest percentages of BeO are used. When a composition of the three ingredients, without beryllium oxide, is selected, which is near the optimum for maximum μ, it has been found that the optimum proportion of co-crystallized BeO is about 3 to about 15 mole percent. When the ternary-system composition is high in iron oxide, the addition of BeO may lower the product μQ; hence, the improved materials should preferably comprise no more than about 70 mole-percent of iron oxide. Furthermore, compositions which have less than about 30 mole-percent of Fe_2O_3 have poor characteristics which are generally not improved sufficiently by the incorporation of BeO to be useful. Perhaps the greatest improvements, on incorporating BeO, occur in those compositions having Curie temperatures near room temperature. As shown in the above tables, the incorporation of BeO beneficially raises the Curie temperature, as well as the product μQ. This useful effect of BeO extends the range of useful compositions which are usable at a given temperature.

The improvement in the product μQ brought about by the inclusion of BeO in the ferrite systems is illustrated graphically in the figure. The figure shows the extent of improvement that it is possible to obtain by adding an optimum amount of BeO to ferrites of the system $NiO:ZnO:Fe_2O_3$. The examples given are those in which an amount of BeO is added such that the maximum increase in value of μQ is obtained. It will be noted that a composition made up of a mixture of 50 mole percent Fe_2O_3, 15 mole percent NiO, and 35 mole percent ZnO can have its μQ product increased by about 530 units when an optimum amount of BeO is included in the composition before crystallization. It will be noted further that, when the compositions contain about 30 mole percent Fe_2O_3, the maximum possible improvement is very small, while, for compositions containing above about 70 mole percent Fe_2O_3, the addition of BeO may lower the μQ product, no matter what amount is added. The figure also illustrates the relative improvement possible to bring about by adding BeO since the increase in value sometimes amounts to several hundred percent.

Although the greatest improvement in magnetic properties has been found when BeO is included in a quaternary system type ferrite, it has also been found that compositions having usefully improved magnetic properties can be obtained by utilizing varying percentages of BeO in a ternary system. Data illustrating examples of various ternary system ferrites, including BeO, are given in Table VIII. It will be noted that some significant improvement is obtained in almost all instances by the addition of BeO although the percentage of improvement is not as great, in general, as when the BeO is added or substituted to form a quaternary system.

Table VIII

Fe_2O_3	MnO_2	ZnO	MgO	NiO	CuO	BeO	$\mu_{eff.}$	Q	μQ
0.45	0.55	----	----	----	----	----	11.9	85	1012
0.45	0.53	----	----	----	----	0.02	11.8	20	236
0.45	0.45	----	----	----	----	0.10	11.2	53	594
0.5	0.5	----	----	----	----	----	13.0	35	405
0.5	0.45	----	----	----	----	0.05	11.6	75	870
0.55	0.45	----	----	----	----	----	12.1	5	61
0.55	0.43	----	----	----	----	0.02	9.1	81	737
0.55	0.40	----	----	----	----	0.05	7.7	66	508
0.45	----	----	----	0.55	----	----	3.5	61	214
0.45	----	----	----	0.50	----	0.05	4.0	115	460
0.50	----	----	----	0.50	----	----	4.3	75	323
0.50	----	----	----	0.45	----	0.05	4.4	90	396
0.50	----	----	----	0.40	----	0.10	4.0	106	424
0.60	----	----	----	0.40	----	----	6.1	94	573
0.60	----	----	----	0.30	----	0.10	3.5	127	445
0.70	----	----	----	0.25	----	0.05	3.6	115	414
0.40	----	----	0.60	----	----	----	5.3	43	228
0.40	----	----	0.45	----	----	0.15	6.5	63	410
0.50	----	----	0.50	----	----	----	6.7	55	369
0.50	----	----	0.40	----	----	0.10	4.2	75	315
0.60	----	----	0.40	----	----	----	3.5	90	315
0.60	----	----	0.30	----	----	0.10	2.8	100	280
0.45	----	----	----	----	0.55	----	7.4	25	185
0.45	----	----	----	----	0.45	0.10	6.4	40	256

Table VIII—Continued

Fe_2O_3	MnO_2	ZnO	MgO	NiO	CuO	BeO	$\mu_{eff.}$	Q	μQ
0.50	----	----	----	----	0.40	0.10	6.4	43	275
0.60	----	----	----	----	0.40	----	10.8	48	518
0.60	----	----	----	----	0.30	0.10	10.4	80	832
0.65	----	----	----	----	0.30	0.05	10.8	67	734
0.5	----	0.25	----	----	----	0.25	5.2	60	312
0.6	----	0.35	----	----	----	0.05	10.9	27	294
0.65	----	0.30	----	----	----	0.05	9.4	42	395

All of the above values were obtained by adding BeO to the various oxide mixtures and then forming compressed bodies and heating in an oxidizing atmosphere. The heating temperature was 1200° C. except that those compositions containing NiO were heated at 1400° C., those containing MgO were heated at 1300° C. and those containing ZnO were heated at 1400° C.

From the data given in the above table, it can be seen that, in some cases, the addition of BeO to a binary system ferrite does not improve the magnetic properties as much as by adding it to a ternary system and in a few cases a slight decrease is noted. However, the proper standard of comparison is a similar body made of powdered iron which was formerly the best material known for high magnetic permeability. In all cases, the materials composed of the ternary system ferrites, including BeO, evidenced improved properties when compared to similar bodies made of powdered iron compressed with a binder. Moreover, for special uses, ternary system products, including BeO, have been found best since the Q values are usually high and the μQ product is also sufficiently high to be useful.

Of all of the above systems which form a part of the present invention, a quaternary system is preferred in which BeO and ZnO are both present. These compositions have proved best as to stability, permeability and Q value. The addition of BeO, and to a lesser extent MgO, has been found to be the only factor which can be added to the ferrite systems in order to improve the product μQ without any loss (or undue loss) of μ.

Addition of many other oxides has been tried. The addition of CaO, BaO, TiO_2, and ZrO_2 usually lowers both effective permeability, μ, and μQ. Addition of any of ThO_2, Sb_2O_3, Al_2O_3, SiO_2, SnO, B_2O_3 or Cr_2O_3 sometimes gives compositions having moderately improved μQ but the effective permeability is usually undesirably lowered.

Although it it is not desired to be restricted to the following theory, it is believed that the beneficial effects of adding BeO (or MgO) to the ferrite compositions may be related to the higher polarizing power of the Be^{++} (or Mg^{++}) ions and the higher melting points of the BeO (or MgO). The polarizing power, for example, is proportional to q/r, where q is the valence charge and r the ionic radius. Be^{++} exhibits an outstandingly high ratio of q/r.

Another interesting and important property of compressed bodies made up of compositions falling within the present invention is that of magnetostriction. Magnetostriction is evidenced by the ability of a body to lengthen in one dimension and contract in another direction when subjected to a magnetic field. Measurements were made on compressed cores of the materials inserted within a hollow tube 1½ inches long and having ¼ inch outside diameter. The cores were rectangular in cross section and had a length of 2½ inches. The tube was wound with a solenoid of 990 turns of No. 30 copper wire. Measurements were taken using two different field strengths, namely, 49.0 oersteds (M_1) and 150.5 oersteds (M_2). The former was obtained by applying a battery current of 0.15 ampere at 1.5 volts and the later field was obtained by applying a battery current of 0.46 ampere at 6 volts to the solenoid.

Some of the core bodies exhibited only positive magnetostriction, as evidenced by increase in length, and others only negative, while some exhibited positive at one field strength and negative at another. In the following table (Table IX) some examples of typical results are given, the positive values, that is lengthening, being designated —P— and negative values, that is shortening, being designated —N—. All values are relative, a bar of nickel of similar dimensions being taken as a standard and assigned the value 4N when subjected to a field of 49 oersteds. A system of levers was used to magnify the amount of dimensional change and the amount of the change was measured by observing the movement of a knife edge connected to the lever system. The units expressed in the table are simply taken in terms of the gradations of the scale of the observing scope.

Table IX

BeO	ZnO	MnO_2	Fe_2O_3	49 oersteds M_1	150.5 oersteds M_2
0.025	0.225	0.25	0.5	0.7N	1.3N
0.075	0.175	0.25	0.5	1.7P	1.0N
0.125	0.125	0.25	0.5	2.0P	0.4N

BeO	ZnO	NiO	Fe_2O_3	M_1	M_2
0	0.35	0.15	0.5	0.5N	0.8N
0.02	0.33	0.15	0.5	1.3N	1.6N
0.125	0.225	0.15	0.5	1.8N	1.8N
0.2	0.15	0.15	0.5	1.3P	0.7P
0.3	0.05	0.15	0.5	0.3P	0.6P

BeO	ZnO	MgO	Fe_2O_3	M_1	M_2
0	0.25	0.25	0.5	0.5N	0.7N
0.02	0.23	0.25	0.5	1.5P	----
0.1	0.15	0.25	0.5	0.75P	0.8P
0.2	0.05	0.25	0.5	1.0P	1.8P
0.1	0.2	0.2	0.5	0.7N	0.8N
0.15	0.15	0.2	0.5	0.6N	1.0N
0.3	0	0.2	0.5	0.25P	0.1P

From the figures in Table IX, it can be seen that, if a body having a certain magnetostriction is desired, it is simply necessary to select the proper composition and prepare a crystalline ferrite body in the manner described herein.

The above examples contained in the several tables are not to be construed as limiting the invention to the specific compositions listed therein. These have been chosen for purposes

of illustration only and have been selected from a larger mass of data. The approximate limits of practical operation have been pointed out elsewhere above and it is these limits as well as those found in the appended claims which it is desired to encompass within the present invention.

In general, the present invention constitutes the discovery that the addition of beryllium oxide to crystalline ferrite materials containing at least one other oxide of a certain group of oxides results in the formation of materials having improved magnetic properties, especially if compared with the best previously known materials formerly used for the same purposes, such as powdered iron. The group of other oxides from which one or more may be selected for inclusion in the compositions is MnO, ZnO, CuO, CdO, NiO and MgO. These may be present in the form of equivalent compounds in the original mixture but must be readily changed to the above oxide form during the heating operation required to bring about the crystal formation.

Especially good results are obtained by selecting two of the above group of oxides together with BeO and experiments indicate that three or more may also be used although, apparently, no additional advantage is gained by so doing.

The improvement in results obtained through use of the present compositions may be in any one or more of several categories; hence, whether or not a certain material constitutes an improved product compared with prior art materials cannot be judged by any one test. Certain of the compositions exhibit exceptionally high values of magnetic permeability, others have exceptionally low loss factor (high Q), some have a desirably high product of these two values, others have desirable magnetostrictive properties and still others have great stability although their permeability or Q values may not be as high as any one of a number of other possible compositions. In some cases, a composition may have exceptionally high Curie temperature and thus be useful for certain applications.

We claim as our invention:

1. A composition of matter comprising the reaction product produced by heating together in a non-reducing atmosphere at temperatures of 900° C. to 1500° C. for 1 minute to 5 hours an intimate mixture of from 30 to 70 mole percent Fe_2O_3, 0.2 to 50 mole percent BeO, and the remainder comprising at least 20 mole percent one other oxide from the class consisting of the oxides of manganese, zinc, magnesium, nickel, cadmium and copper.

2. A composition, according to claim 1, in which the amount of BeO is from about 0.2 to about 30 mole percent.

3. A composition, according to claim 1, in which the amount of BeO is about 3 to about 15 mole percent.

4. A composition of matter comprising the reaction product produced by heating together in a non-reducing atmosphere at temperatures of 900° C. to 1500° C. for 1 minute to 5 hours an intimate mixture of about 30 to 70 mole percent Fe_2O_3, about 0.2 to about 50 mole percent BeO, and the remainder comprising at least 20 mole percent of one oxide from the class consisting of MnO_2, ZnO, MgO, NiO, CuO and CdO.

5. A composition of matter comprising the reaction product produced by heating together in a non-reducing atmosphere at temperatures of 900° C. to 1500° C. for 1 minute to 5 hours an intimate mixture of about 30 to about 70 mole percent Fe_2O_3, about 0.2 to 50 mole percent BeO, and the remainder comprising at least 20 mole percent of two oxides of different metals from the class consisting of oxides of manganese, zinc, magnesium, nickel, copper and cadmium.

6. A composition of matter comprising the reaction product produced by heating together in a non-reducing atmosphere for 1 minute to 5 hours at temperatures of 900° C. to 1500° C. an intimate mixture of about 30 to about 70 mole percent Fe_2O_3, about 0.2 to about 50 mole percent BeO, and the remainder comprising at least 20 mole percent of ZnO and at least one oxide from the class consisting of the oxides of manganese, magnesium, nickel, copper and cadmium.

7. An article of manufacture characterized by having improved magnetic properties comprising a compressed body of material of predetermined shape, said material comprising a reaction product produced by heating together in a non-reducing atmosphere at a temperature of 900° C. to 1500° C. for 1 minute to 5 hours an intimate mixture of 30 to 70 mole percent Fe_2O_3, 0.2 to 50 mole percent BeO and at least 20 mole percent of an oxide from the class consisting of the oxides of manganese, zinc, magnesium, nickel, copper and cadmium.

8. An article of manufacture characterized by having improved magnetic properties comprising a compressed body of material of predetermined shape, said material comprising a reaction product produced by heating together in a non-reducing atmosphere at a temperature of 900° C. to 1500° C. for 1 minute to 5 hours an intimate mixture of 30 to 70 mole percent Fe_2O_3, 0.2 to 50 mole percent BeO, the remainder comprising at least 20 mole percent ZnO and at least one other oxide from the class consisting of the oxides of manganese, magnesium, nickel, copper and cadmium.

9. A method of forming a core body characterized by having improved magnetic properties comprising preparing an intimate mixture of 30 to 70 mole percent Fe_2O_3, 0.2 to 50 mole percent BeO and at least 20 mole percent of an oxide from the class consisting of MnO_2, ZnO, MgO, NiO, CuO and CdO, compressing said mixture to form a coherent molded body of predetermined shape, subjecting said molded body to a temperature of 900° C. to 1500° C. in a non-reducing atmosphere for 1 minute to 5 hours to form a crystalline substance having a definite chemical composition, and cooling said crystalline substance.

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