THE MAGNETIC PROPERTIES OF RARE-EARTH METALS

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Substances may be divided into three classes according to their magnetic properties: diamagnetic, paramagnetic, and ferromagnetic. According to most theories of magnetism, all substances possess the diamagnetic property. In addition to being diamagnetic any substance may be paramagnetic or ferromagnetic also. The latter properties in any substance, however, predominate to such an extent as to completely mask the diamagnetic property.

Since the magnetic properties of substances must be intimately connected with their molecular or atomic structure, it is important to ascertain their magnetic properties along with other properties. One of the principal difficulties in the way of obtaining reliable magnetic data is the inability to obtain pure samples of the substances. Iron impurities are especially troublesome, since a milligram of pure iron has as great magnetic effect as one thousand grams of most dia- or para-magnetic substances. However, if the iron is present as an alloy its effect is very greatly reduced. Most of the iron compounds are paramagnetic, some of them having very low magnetic susceptibility.

For many years Dr. B. S. Hopkins and his co-workers of the Chemistry Department in the University of Illinois have been interested in the production and purification of rare-earth compounds and elements. It has been the privilege of the author to obtain samples of these compounds and elements as they have been made, in order to determine their magnetic properties. I herewith acknowledge my indebtedness to these scientists for their cooperation.

The work to be reported on at this time concerns the magnetic properties of some rare-earth elements, namely, cerium, lanthanum, praseodymium, and yttrium. The magnitude of the susceptibilities of these substances is approximately one-millionth that of iron, and therefore they are classed as paramagnetic. However, unlike most paramagnetic substances, the susceptibility of the above rare-earth elements does not remain constant with varying field strengths but varies in a manner similar to that of ferromagnetic substances. This variation for cerium is shown in Table I.

In view of what has been said about the effect of impurities, one is naturally led to question whether or not there can be present an impurity such as iron, or other strongly magnetic substance, to such an extent as to cause the variation.

The rare-earth metals used in this investigation were prepared by Professor H. C. Kremers of the Department of Chemistry in such manner as to guard against the presence of any iron. The compounds were carefully prepared and the metal deposited electrolytically. To have the effect shown in Table I the iron, if present in the form of an alloy, would have to constitute an appreciable percentage of the total. This is altogether unlikely so that one must conclude that if iron is present at all it is present in the free state.

TABLE I

MAGNETIC SUSCEPTIBILITY OF CERIUM

Current in amperes in electromagnet	$X_m \times 10^6$
0.3	138.0
0.5	81.0
0.8	52.0
1.0	45.0
2.0	30.5
3.0	25.5
5.0	21.8
6.0	20.9
7.0	20.4

To test whether iron forms alloys with the rare-earth metals, experiments were conducted on mischmetal, which is a substance consisting mainly of cerium and yttrium. Two samples of commercial mischmetal were tested and analyzed. To commercial mischmetal varying amounts of pure iron were added. Each sample was tested and analyzed. The results are shown in Table II. From the results for the susceptibility one must conclude that iron, in amounts up to seven percent at least, alloys with the mischmetal to form paramagnetic compounds.

TABLE II

MAGNETIC SUSCEPTIBILITY OF MISCHMETAL PLUS IRON

(Current in electro-magnet = 6 amperes)

Sample	Percent Fe	$X_m \times 10^6$
Commercial No. 1	2.18	28.4
Commercial No. 2	2.32	29.8
Prepared No. 1	3.14	30.8
Prepared No. 2	4.16	39.6
Prepared No. 3	5.20	45.3
Prepared No. 4	6.46	50.0
Prepared No. 5	6.90	62.5

Table III shows the behavior of the prepared sample of mischmetal containing 6.46% Fe by analysis. Remembering that pure iron is about one million times as magnetic as mischmetal, it is evident that the iron alloys with the mischmetal to form a paramagnetic substance.

TABLE III

MAGNETIC SUSCEPTIBILITY OF MISCHMETAL-IRON ALLOY NO. 4

Current in amperes in electro-magnet	$X_m \times 10^6$
0.3	87.0
0.5	66.0
0.8	54.0
1.0	53.0
2.0	51.8
3.0	51.3
4.0	50.6
5.0	50.2
6.0	50.0

The behavior of lanthanum, praseodymium, and yttrium was similar to that of cerium except as to magnitude. The values of the susceptibility for very strong fields is shown in Table IV.

TABLE IV

MAGNETIC SUSCEPTIBILITY OF RARE-EARTH METALS AT SATURATION

Substance	$X_m \times 10^6$
Cerium	20.4
Lanthanum	31.6
Praseodymium	31.0
Yttrium	67.0

Since the cerium in Table I contains less than 0.01% Fe and, furthermore, since this amount is present in the form of a paramagnetic alloy, one must conclude that the cerium itself behaves like ferromagnetic substances in that its susceptibility varies with the field strength.