CHAPTER 1

INTRODUCTION

1.1 History of Magnetism

It was probably the Greeks who first discovered the properties of magnetite. This mineral was named after the name Magnesia, the place where it was mined, and the phenomenon of the various properties associated with it is called "magnetism". Socrates mentioned that magnetite can induce iron to become magnetic. Permanent and induced magnetism represent two of man's earliest scientific discoveries. Of the early natural philosophers who studied magnetism, the most famous is William Gilbert (1540-1603). He was the first to consider the earth as a huge magnet. P. Pere grines discovered magnetic poles around the year 1269 A.D. However, the beginning of a theoretical understanding of magnetism was set up by Coulomb (1736-1806) in his experimental results on the forces between magnetic poles of long thin steel rods.

In general, magnetism originates from the magnetic moment due to the rotational motion of charged particles, the basic concept which is accounted for by the molecular theory of Ampere. The correct formulation of the theory of magnetism requires quantum mechanics since a strictly classical system in thermal equilibrium cannot display a magnetic moment, even in a magnetic field[1].

1.2 The Classification of Magnetism

The magnetic moment of a magnetic material arises from the sum of the magnetic moments of the composing atoms which have electron spins and orbital motion of electrons about nuclei. The classification of the magnetic materials is most naturally based on the effect of an applied magnetic field on their magnetic moments. This effect is characterized by the magnetic susceptibility, χ, defined as

$$\chi = \frac{M}{H_o}, \qquad (1.1)$$

where M is the magnetization, or magnetic moment per unit volume and H_o is the applied magnetic field. Magnetic materials can be classified into diamagnetic and paramagnetic materials.

Diamagnetic materials are substances with a negative susceptibility, i.e., the induced magnetic moment is in the opposite direction of the applied field. Diamagnetism originates from the change in the orbital moment induced by the application of

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[1] The theorem due to J.H. Leeuwen, is treated by J.H. Van Vleck, Electric and Magnetic Susceptibilities (Oxford: 1932), pp. 94-104.

an external field. Diamagnetism always exists in any substances which have both diamagnetic and paramagnetic contributions. However, the diamagnetism is in general so weak that paramagnetism overwhelms the substances. Consequently, it is difficult to measure accurately the diamagnetic susceptibility of these substances.

Paramagnetism occurs only in substances with permanent magnetic moments of individual atoms or molecules. The paramagnetic susceptibility is positive and temperature dependent according to the relation

$$\chi = \frac{C}{T} \qquad (1.2)$$

which is known as the Curie law with C is a constant called the Curie constant. In paramagnetic materials, the applied magnetic field tries to align the magnetic moments in its direction but this effect is opposed by thermal agitation which has the tendency to preserve the random orientation of the magnetic moments. However, some paramagnetic materials exhibit paramagnetism with the susceptibility inversely proportional to T only in a high temperature range and lose their paramagnetic behaviors when they are cooled to a sufficiently low temperature. These substances can have a spontaneous magnetic moment or a magnetic moment even in zero applied magnetic field. These substances may be divided into three main classes: ferromagnetic, antiferromagnetic and ferrimagnetic substances.

A ferromagnetic material has a complete parallel alignment of the strongly coupled dipole moments at absolute zero. As the temperature increases, the spontaneous magnetization is reduced by thermal agitation until at an elevated temperature known as the Curie temperature, it becomes zero. The material is then paramagnetic with a susceptibility given approximately by the Curie-Weiss law[2]:

$$\chi = \frac{C}{T - \theta} , \qquad (1.3)$$

where C is the Curie constant and θ is a certain kind of characteristic transition temperature of the material observed from experimental results generally called the paramagnetic Curie temperature.

The phenomenon of antiferromagnetism occurs in materials in which an antiparallel arrangement of the strongly coupled atomic dipoles is favored. Néel (1932) originally considered an antiferromagnetic lattice as composed of two equivalent interpenetrating nearest neighbouring sublattices. The magnetic atoms are arranged so as to give parallel magnetic moments in the same

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[2] A.H. Morrish, The Physical Principles of Magnetism (New York: John Wiley & sons, Inc., 1965), pp. 268-269.

sublattice but antiparallel in different ones. Consequently, the spontaneous magnetization of the two equivalent sublattices cancels out giving zero net magnetic moment at all temperatures. The spontaneous magnetization of each sublattice reaches its maximum value at absolute zero and decreases by means of thermal agitation as the temperature increases. At a certain temperature, usually called the Néel temperature, the ordered arrangement becomes completely random and the spontaneous magnetization of each sublattice vanishes. The paramagnetic susceptibility above the Néel temperature is given by[3]

$$\chi = \frac{C}{T + \theta} \cdot \qquad (1.4)$$

The last type of magnetism is ferrimagnetism as called by Néel[4,5]. This phenomenon may be considered as a generalization of antiferromagnetism in which the two sublattices have different magnetization. Accordingly, there will be a net magnetic moment which gives rise to an appreciable net spontaneous magnetization at absolute zero. In virtue of thermal agitation, just as in ferro- and antiferromagnetism, increasing in temperatures lowers the spontaneous magnetization and at the so called Curie or Néel

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[3] Ibid., pp. 448-449.

[4] L. Néel, Annals of Physics (Paris) 3, 137 (1948).

[5] L. Néel, "Some New Results on Antiferromagnetism and Ferromagnetism," Review of Modern Physics 25, 58 (1953).

temperature, the spontaneous magnetization vanishes. The Curie-Weiss law fails to represent the temperature dependence of the paramagnetic susceptibility of a ferrimagnet above the Neel temperature and this is a distinguishing characteristic of a ferrimagnet. Neel has shown that χ^{-1} satisfies the equation[6]

$$\frac{1}{\chi} = \frac{T}{C} + \frac{1}{\chi_0} - \frac{\sigma}{T - \theta'} . \qquad (1.5)$$

In spite of having a spontaneous magnetization as a common feature, ferromagnetic, antiferromagnetic, and ferrimagnetic materials have distinct behaviors of the spontaneous magnetization. Also, their susceptibility has different temperature dependence except at high temperatures, they exhibit the same paramagnetic behavior. This is illustrated by Fig. 1.

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[6] See also A.H. Morrish, <u>op. cit.</u>, pp. 491-493.

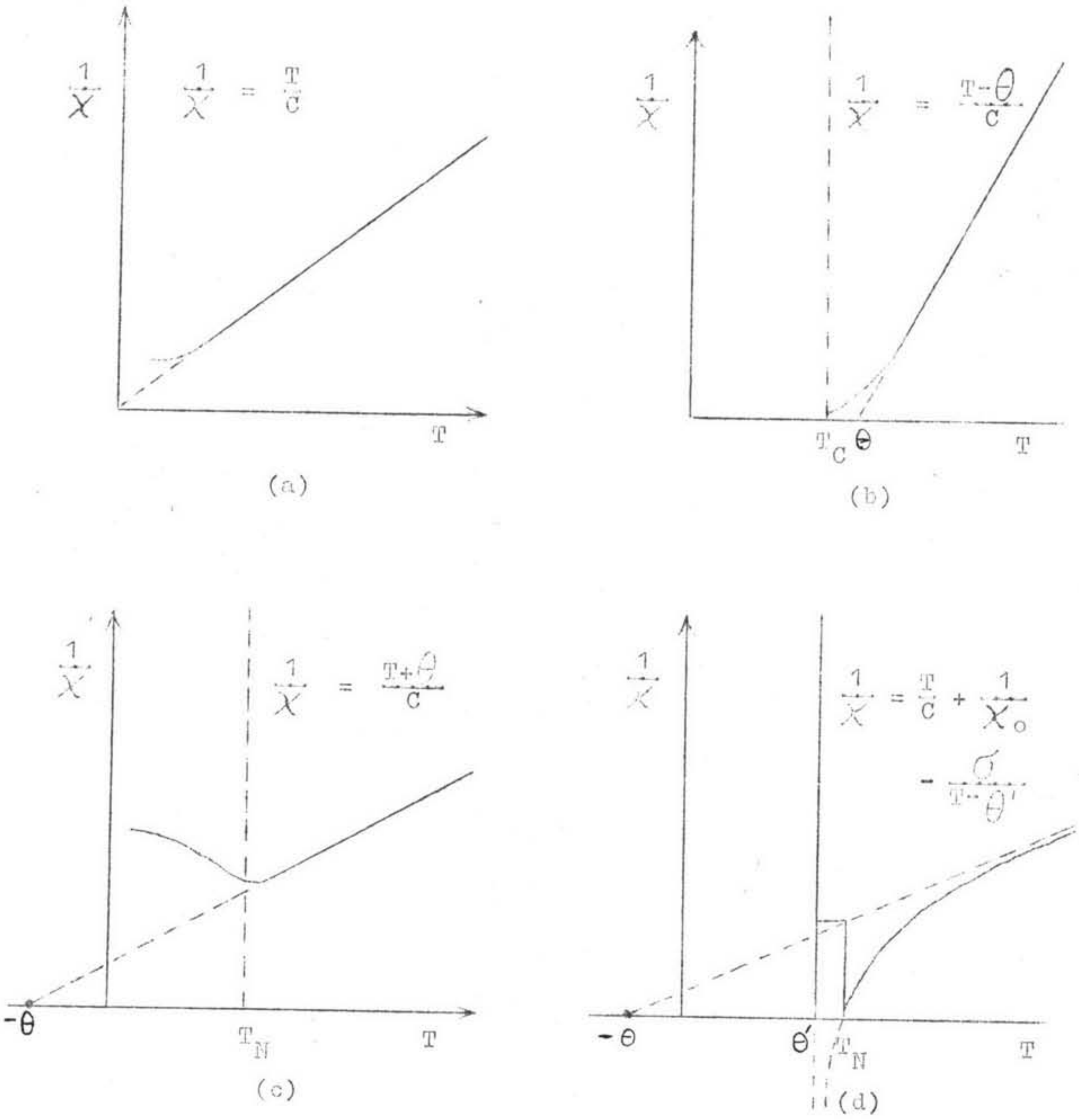

Fig. 1 Inverse magnetic susceptibility as a function of temperature. (a) Paramagnet. (b) Ferromagnet. (c) Antiferromagnet. (d) Ferrimagnet.