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APPENDIX A

Antiferromagnetism

In general, materials can be classified according to their magnetic behavior into diamagnetic, paramagnetic, ferromagnetic, antiferromagnetic, and ferrimagnetic. In diamagnetic materials magnetic effects are weak. Although the net magnetic moment is zero in the absence of an external magnetic field, an applied field causes the spin moment to slightly exceed the orbital moment, resulting in a small net magnetic moment which opposes the applied field. In materials which net magnetic moment is not zero in the absence of an external magnetic field, when an external field is applied , the spin moment tends to line up with the field. In these materials magnetic effect is significant, and substances are called paramagnetic. A ferromagnet has a spontaneous magnetic moment - a magnetic moment even in zero applied magnetic field. These materials have a rigid parallel spin moment over region. In ferrimagnetic substances the spin moments of adjacent atoms are aligned opposite but the moments are not equal so that there is a net magnetic moment that is less than in ferromagnetic materials. In antiferromagnetic materials the spin moments are ordered in an antiparallel arrangement with zero net magnetic moment. All of the spin arrangement are sketched in Fig. A.1

↑↑↑↑↑	↓↑↓↑↓↑	↑↓↑↓↑↓
Simple ferromagnet	Simple antiferromagnet	Ferrimagnet

Fig. A.1 Ordered arrangement of spin moment

In 1932 Neel (Neel, 1932) was first to show that antiferromagnetic system has a critical temperature, now called the Neel temperature T_N, below which spin moments are arranged alternately parallel and antiparallel. Above T_N the substance is paramagnetic.

An antiferromagnetic does not have any magnetic moment, so that the system does not show any permanent magnetization. All that is observed is a change in susceptibility χ in the presence of a small magnetic field. This behavior is shown in Fig.A.2 for MnF_2, whose Neel temperature is T_N = 72 K. Note that the susceptibility does not diverge at the transition point.

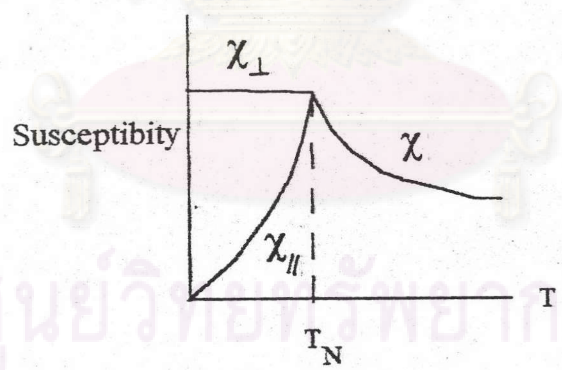

Fig. A.2 Susceptibility χ versus T for MnF_2. The quantities $\chi_{//}$ and $\chi_\perp$ refer to susceptibility for the field parallel to and perpendicular to the spontaneous spin direction, respectively. (Omar, 1975)

This result is interesting, in that it depends on the orientation of magnetic field relative to the direction of magnetization of the two sublattices. When magnetic field is parallel to spin moment the susceptibility $\chi_{//}$ goes to zero at T = 0. This is because the internal field is so strong that it prevents any spin in the sublattice from turning over. On the other hand, $\chi_{\perp}$ at T = 0 is the same as the value it would have at T_N ; the spin moment of the sublattice normal to the applied field exerts only a feeble opposition to their magnetization being slightly turned in the field direction.

Since the net magnetization is zero for an antiferromagnetic, this can be distinguished from a nonmagnetic state by the behavior of susceptibility as a function of temperature. A paramagnetic substance obeys the Curie law $\chi \ \alpha$ 1/T all temperature, while an antiferromagnetic substance exhibits the behavior shown in Fig.A.2 One can also ascertain the magnetic order in the antiferromagnetic phase by means of neutron diffraction. Below the Neel temperature, the spin moment form what amounts to two interpeentrating magnetic lattices of opposite spin, which give rise to Bragg reflection of the neutron beam.

APPENDIX B

Consider $I = 2\pi T_c \sum_{n=0}^{\omega_D/2\pi T_c - 1/2} 1/\omega_n$

where ω_D is Debye cuttoff frequency that dependence of electron-phonon interaction and $\omega_n = \pi T(2n+1)$.

we get

$$I \quad = \quad 2 \sum_{n=0}^{\omega_D/2\pi T_c - 1/2} 1/(2n+1)$$

In this case, $\omega_D/2\pi T_c - 1/2 \rightarrow \infty$

$$\sum_{n=0}^{\omega_D/2\pi T_c - 1/2} 1/(2n+1) = 1 + 1/3 + 1/5 + 1/7 + \ldots + 1/(\omega_D/\pi T_c)$$

$$= 1 + 1/2 + 1/3 + 1/4 + \ldots + 1/(\omega_D/\pi T_c) - [1/2 + 1/4 + 1/6 + \ldots + 1/(\omega_D/\pi T_c - 1)]$$

$$= \sum_{n=1}^{\omega_D/\pi T_c} 1/n - [1/2] \sum_{n=1}^{\omega_D/2\pi T_c - 1/2} 1/n$$

$$= \gamma + \ln(\omega_D/\pi T_c) - [1/2][\gamma + \ln(\omega_D/2\pi T_c - 1/2)]$$

where

$\sum_{m=1}^{N} 1/m = \gamma + \ln N$ here $N \rightarrow \infty$ and $\gamma = 0.5772156649$

(Jahnke and Emde,1945)

Finally, we have

$$
\begin{aligned}
I &= 2\{\ \gamma/2 + \ln[(\omega_D/\pi T_c)(\omega_D/2\pi T_c - 1/2)^{-1/2}]\ \} \\
&= 2\{\ \gamma/2 + \ln[2\omega_D/\pi T_c]\ \} \\
&= \ln(1.13\omega_D/\pi T_c\ \}
\end{aligned}
$$

CURRICULUM VITAE

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