Magnetic properties of materials

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Part 2. Types of magnetism (or $-1 \leq \chi < \inf$)

$$I = e\frac{eB}{2m_e}\frac{1}{2\pi} \tag{2.1}$$

$$m = \frac{e^2Br^2}{4m_e} \tag{2.2}$$

$$M = NZ\frac{e^2\langle r^2\rangle}{4m_e}B \tag{2.3}$$

$$\chi = \frac{M}{H} = \frac{M\mu_0}{B} = NZ\frac{\mu_0 e^2\langle r^2\rangle}{4m_e}. \tag{2.4}$$

$$n(\downarrow) = N\frac{\exp\left(+\frac{\mu_B B}{k_B T}\right)}{\exp\left(-\frac{\mu_B B}{k_B T}\right) + \exp\left(+\frac{\mu_B B}{k_B T}\right)} \tag{2.5}$$

$$n(\uparrow) = N\frac{\exp\left(-\frac{\mu_B B}{k_B T}\right)}{\exp\left(-\frac{\mu_B B}{k_B T}\right) + \exp\left(+\frac{\mu_B B}{k_B T}\right)} \tag{2.6}$$

$$M = \mu_B(n(\downarrow) - n(\uparrow)) = N\mu_B\frac{\exp\left(+\frac{\mu_B B}{k_B T}\right) - \exp\left(-\frac{\mu_B B}{k_B T}\right)}{\exp\left(-\frac{\mu_B B}{k_B T}\right) + \exp\left(+\frac{\mu_B B}{k_B T}\right)} \tag{2.7}$$

$$M = N\mu_B \tanh\left(\frac{\mu_B B}{k_B T}\right) \tag{2.8}$$

$$M = \frac{N\mu_B^2 B}{k_B T} \tag{2.9}$$

$$\chi = \frac{N\mu_B^2\mu_0}{k_B T} = \frac{C}{T} \tag{2.10}$$

$$\chi = \frac{Nm^2\mu_0}{k_B T} \tag{2.11}$$

$$n(\text{flip}) = \mu_B B\frac{g(E_F)}{2} \tag{2.12}$$

$$M = \mu_B^2 \frac{3N}{2E_F} B \tag{2.13}$$

$$\chi(\text{Pauli}) = \mu_0 \mu_B^2 \frac{3N}{2E_F} \tag{2.14}$$

$$\chi(\text{Pauli}) = \frac{3}{2} \frac{N\mu_B^2 \mu_0}{k_B T_F} \tag{2.15}$$

$$U_{ex}(ij) = -2JS_i \cdot S_j \tag{2.16}$$

$$U_{ex}(ij) = -m_i \cdot m_j \frac{2J}{g^2 \mu_B^2} \tag{2.17}$$

$$U_{ex}(ij) = -m_i \cdot \frac{2\bar{J}}{g^2 \mu_B^2 N} M \tag{2.18}$$

$$M = \chi H = \frac{C}{T} H = \frac{C}{T} \frac{B}{\mu_0} \tag{2.19}$$

$$M = \frac{C(B_{\text{app}} + B_{\text{int}})}{\mu_0 T} = \frac{C(B_{\text{app}} + \lambda M)}{\mu_0 T} \tag{2.20}$$

$$M = \frac{C}{\mu_0 T - C\lambda} B_{\text{app}} \tag{2.21}$$

$$\chi = \frac{C}{T - C\lambda/\mu_0} \tag{2.22}$$

$$\chi = \frac{C}{T - \theta_W} \tag{2.23}$$

$$\theta_W = \frac{N\mu_B^2 \lambda}{k_B} \approx \frac{\bar{J}}{2k_B} \tag{2.24}$$

$$\chi = \frac{C}{T + \theta_N} \tag{2.25}$$

$$U = \frac{1}{2} \mu_0 H^2 \tag{2.26}$$

$$E_K = K_1(\alpha_1^2 \alpha_2^2 + \alpha_2^2 \alpha_3^2 + \alpha_1^2 \alpha_3^2) + K_2(\alpha_1^2 \alpha_2^2 \alpha_3^2) + \ldots \tag{2.27}$$

$$U_{ex}(ij) = -2JS^2 \cos(\delta\theta) \tag{2.28}$$

$$U_{ex}(ij) \approx JS^2(\delta\theta)^2 + \text{constant} \tag{2.29}$$

$$U_{ex} = \frac{JS^2\pi^2}{Na^2} \tag{2.30}$$

$$U_{\text{total}} = \frac{JS^2\pi^2}{Na^2} + KNa \tag{2.31}$$

$$\frac{dU_{\text{total}}}{dN} = -\frac{JS^2\pi^2}{N^2a^2} + Ka = 0 \tag{2.32}$$

$$N = \pi S\sqrt{\frac{J}{Ka^3}} \tag{2.33}$$

$$w = \pi S\sqrt{\frac{J}{Ka}} \tag{2.34}$$

$$U_{\text{total}} = 2\pi S\sqrt{\frac{JK}{a}}. \tag{2.35}$$

$$U_{\text{mag}} = \mathbf{M}\cdot\mathbf{B} = \mu_0 M_s H\cos(\theta - \phi) \tag{2.36}$$

$$U = \mu_0 M_s H\cos(\theta - \phi) + K\sin^2\theta \tag{2.37}$$