หอสมุดกลาง สถาบันวิทยบริการ จุฬาลงกรณ์มหาวิทยาลัย

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APPENDIX

Derivation of Eq. (3.44)

Let us consider the sum

$$N = \sum_k \bar{n}_k$$

The usual way of calculating $\sum_k$ is to replace

$$\frac{1}{\Omega}\sum_k \quad \text{by} \quad \frac{1}{(2\pi)^3} \; d^3\vec{k}\ldots \quad = \int \rho(\epsilon)\,d\epsilon$$

where Ω is volume and $\rho(\epsilon)$ is the density of states, therefore

$$\sum_{k,\omega_n} \frac{1}{(\omega_n^2 + \epsilon_{ck}^2)} = N_c \sum_{\omega_n} \int \frac{d\epsilon}{(\epsilon^2 + \omega_n^2)}$$

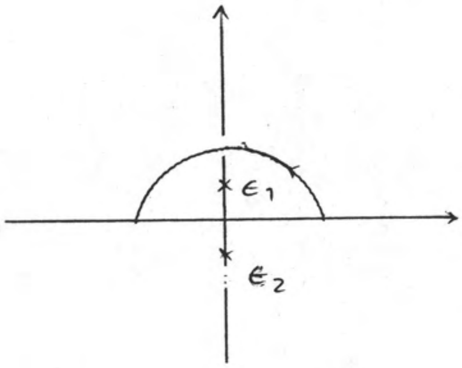
$$= N_c \sum_{\omega_n} I$$

where $$I = \int_{-\infty}^{\infty} \frac{d\epsilon}{(\epsilon^2 + \omega_n^2)}$$

$$= \int_{-\infty}^{\infty} \frac{d\epsilon}{(\epsilon - i\omega_n)(\epsilon + i\omega_n)} \qquad (A.1)$$

This integral can be easily done in the complex ϵ-plane. The poles are at

$$\epsilon_1 = i\omega_n \qquad \epsilon_2 = -i\omega_n \tag{A.2}$$



$$I = 2\pi i \,\mathrm{Res} \left. \frac{1}{(\epsilon-\epsilon_1)(\epsilon-\epsilon_2)} \right|_{\epsilon=\epsilon_1}$$

$$= \frac{2\pi i}{\epsilon_1-\epsilon_2} = \frac{2\pi i}{2i\omega_n} = \frac{\pi}{\omega_n} \tag{A.3}$$

$$\sum_{k,\omega_n} \frac{1}{(\omega_n^2+\epsilon_{ck}^2)} = N_c\pi \sum_{\omega_n} \frac{1}{\omega_n} \tag{A.4}$$

where $\omega_n = (2n+1)\pi T$ (A.5)

$$F = 2\pi T_c \sum_{n=0} \frac{1}{\omega_n}$$

consider

$$I = 2\pi T_c \sum \frac{1}{\omega_n}$$

It is however natural to introduce cutoff $\omega_m(\max) = \omega_D$ which is physically due to the frequency dependence of electron-phonon interaction.

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

$$= 2\sum_{n=0}^{\omega_D/2\pi T_c - 1/2} \frac{1}{2n+1}$$

$$I/2 = \sum_{n=0}^{\omega_D/2\pi T_c - 1/2} \frac{1}{2n+1} \qquad \text{(A.6)}$$

$$= \left[\sum_{n=0}^{\infty} - \sum_{\omega_D/2\pi T_c - 1/2}\right] \frac{1}{(2n+1)}$$

$$= \sum_{n=0} \frac{1}{2n+1} - \lim_{N\to\infty} \left[\sum_{\omega_D/2\pi T}^{N} \frac{1}{2n+1}\right]$$

$$= \left(\frac{1}{1} + \frac{1}{3} + \frac{1}{5} + \ldots \frac{1}{\infty}\right) - \frac{1}{2}\ln(2n+1) \Big|_{\omega_D/2\pi T_c}^{N}$$

$$= \left(1 + \frac{1}{2} + \frac{1}{3} + \ldots 1\right) - \left(\frac{1}{2} + \frac{1}{4} + \frac{1}{6} + \ldots\right) - \frac{1}{2}\ln 2N - \ln(\omega_D/\pi T_c)\Big|$$

$$I/2 = \sum_{m=1}^{\infty} \frac{1}{m} - 1 + \frac{1}{2}\ln(\omega_D/\pi T_c) - \frac{1}{2}\ln 2N$$

$$I = 2\sum_{m=1} \frac{1}{m} - 2 + \ln(\omega_D/\pi T_c) - \ln 2N \tag{A.7}$$

$$I = 2[\sum_{m=1} \frac{1}{m} - 1] + \ln(\omega_D/\pi T_c) - \ln 2N$$

$$= 2 \lim_{N\to\infty} \sum_{m=1}^{N} \frac{1}{m} - 2 + \ln(\omega_D/\pi T_c) - \ln 2N$$

$$= 2\left[\gamma + \lim_{N\to\infty} \ln N\right] - 2 + \ln(\omega_D/\pi T_c) - \ln 2N$$

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

$$I = \ln(\omega_D 1.13/T_c) \tag{A.8}$$

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