

## KALMAN KNIZHNIK - KITTEL AND KROEMER SOLUTIONS

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### K&K 2.1

#### Part a

Suppose  $g(U) = CU^{2N/2}$ , where  $C$  is a constant and  $N$  is the number of particles. Show that  $U = \frac{3}{2}N\tau$ .

We use the definition of temperature as

$$\left. \frac{\partial \sigma}{\partial U} \right|_N = \frac{1}{\tau} \quad (1)$$

So, let's calculate  $\sigma$ .

$$\sigma = \ln(g) = \frac{3N}{2} \ln(U) + \ln(C) \quad (2)$$

Therefore,

$$\frac{\partial \sigma}{\partial U} = \frac{3N}{2U} = \frac{1}{\tau} \quad (3)$$

So finally,

$$U = \frac{3}{2}N\tau \quad \square \quad (4)$$

#### Part b

Show that  $\partial^2 \sigma / \partial U^2|_N$  is negative. This form of  $g(U)$  actually applies to an ideal gas. Referring to the definition of  $\frac{\partial \sigma}{\partial U}$  in equation 3 and taking another derivative:

$$\frac{\partial^2 \sigma}{\partial U^2} = -\frac{3N}{2U^2} < 0 \quad \square \quad (5)$$

This suggests that the temperature of the system will increase with increasing  $U$ .

### K&K 2.2

Find the equilibrium value at temperature  $\tau$  of the fractional magnetization  $M/Nm = 2\langle s \rangle/N$  of the system of  $N$  spins each of magnetic moment  $m$  in a magnetic field  $B$ . The spin excess is  $2s$ . Take the entropy as the logarithm of the multiplicity as given in 1.35:  $\sigma(s) \approx \log\{g(N, 0)\} - 2s^2/N$ .

The energy of a single magnetic moment  $m$  in a magnetic field  $B$  is  $U = -m \cdot B$ . A spin excess of  $2s$  means that there are  $2s$  spins with this magnetic moment. In other words, there could be, say,  $2s$  particles of magnetic moment  $m$  and  $1s$  particles of magnetic moment  $-m$ . The energy would cancel for all but  $2s$  particles. Thus, the total energy of the system is  $U = -2smB$ . Therefore,  $s = -U/2mB$ . So the entropy is

$$\sigma = \sigma_0 - \frac{2s^2}{N} = \sigma_0 - \frac{U^2}{2m^2 B^2 N} \quad (6)$$

Since  $1/\tau = \partial \sigma / \partial U$ , we find

$$\frac{\partial \sigma}{\partial U} = -\frac{U}{m^2 B^2 N} = \frac{1}{\tau} \Rightarrow U = -\frac{m^2 B^2 N}{\tau} \quad (7)$$

Finally, we know that  $U = -MB$  since the energy is the total magnetization times the magnetic field. Therefore,

$$-\frac{m^2 B^2 N}{\tau} = -MB \Rightarrow \frac{M}{Nm} = \frac{mB}{\tau} \quad \square \quad (8)$$

Note that the magnetic susceptibility obeys Curie's law  $\chi \sim M/B \sim 1/\tau$ .

### K&K 2.3

#### Part a

Find the entropy of a set of  $N$  oscillators of frequency  $\omega$  as a function of the total

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