ASSESSMENT

Solid-state physics

Assignment 1: Debye, Drude, Sommerfeld, and chemistry

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Due: 1700, September 13, 2021

Exercise 1 *Debye* (6 points)

(i) What are the assumptions of the Debye model?

(ii) Write an expression for the number of modes in a two-dimensional system, and thus determine the *Debye wavenumber* (the wavenumber which corresponds to the Debye frequency).

(iii) Provide a brief discussion of which elements you would expect to have a high Debye temperature, and which elements you would expect to have a low Debye temperature.

Note: your reasoning is important, not the actual elements!

Exercise 2 *Drude: mixed ion-electron conductors (MIECs)* (8 points)

MIECs are a fascinating brand of material with the property that both electrons and ions can be charge carriers. You can probably imagine that this would be a desirable property under some situations, for example, in a fuel cell. An example MIEC is $SrTiO_3$, the material of which I showed an atomic resolution micrograph in the introductory video.

Within a MIEC, assume that free electrons and ions have a densities $n_{e,i}$, scattering times $\tau_{e,i}$, masses $m_{e,i}$ and charges $-e, +e$ respectively.

(i) Calculate the electrical resistivity σ

(ii) Calculate the thermal conductivity κ

(iii) What is the Weidemann-Franz law? Does it hold in this situation?

(iv) If we consider a magnetic field applied in the $+z$ direction, we need only consider the conductivity in x and y and can write

$$\rho = \begin{pmatrix} \frac{m}{nq^2\tau} & \frac{Bq}{n} \\ -\frac{Bq}{n} & \frac{m}{nq^2\tau} \end{pmatrix}$$

which is true for both charge carrier species. Use this result to calculate the resistivity matrix in the case of a MIEC.

Exercise 3 *Sommerfeld* (10 points)

(i) In your own words, explain what is the Fermi energy, Fermi temperature and the Fermi surface

(ii) Write an expression for the number of states for a gas of free electrons in three dimension and use this to calculate the Fermi wavenumber and Fermi Energy

(iii) Using the previous result, estimate the value of the Fermi energy for Caesium

(iv) Obtain an expression for the density of states at the Fermi surface of a **two-dimensional** free-electron gas.

(v) Using the above result, show that for a two-dimensional free-electron gas that the chemical potential μ is independent of temperature when $T \ll \mu$

Exercise 4 *Chemistry* (6 points)

(i) Explain using the simplest language you can muster why is there periodic table important?

(ii) Choose a naturally occurring element with a high atomic number and use Madelung's Rule to deduce the shell filling configuration.

For lols: the highest unique atomic number will be awarded an additional prize

(iii) Using any tools at your disposal (i.e. use a computer) produce a plot of the energy eigenstate described by $|5, 2, 0\rangle$. You must include your code and you will be partially assessed on presentation: producing content that is digestible and visually pleasing is an important part of modern science!