

FSK324 Test 1

Solid State Physics

Time: 90 minutes

Total marks: [100]

Section A - The crystalline state: Answer *all* questions in this section

- i.) Distinguish between amorphous, poly-crystalline and single crystal materials [3]
 - ii.) Define the terms *vacancy* and *Schottky defect* [2]
- i.) Define a Wigner-Seitz (WS) unit cell and describe its construction [3]
 - ii.) How is the WS unit cell related to a Brillouin zone? [3]
- Let $\bar{A} = (\bar{a}_1, \bar{a}_2, \bar{a}_3)$ and $\bar{B} = (\bar{b}_1, \bar{b}_2, \bar{b}_3)$ define basis vectors in real and reciprocal lattice spaces respectively. Prove that $\bar{b}_i \cdot \bar{a}_j = 2\pi\delta_{ij}$ where δ_{ij} is Kronecker's delta. [5]
- FCC gold has density 19.3 gcm^{-3} and atomic number 197. Calculate
 - i.) the distance between the (111) planes [3]
 - ii.) the atomic radius of the gold atom, assuming hard spheres. [3]
- Show that for the HCP structure $a = b \neq c$, where $c/a = \sqrt{8/3}$. [8]
- Sodium undergoes a Martensitic transformation from BCC ($a = 0.423 \text{ nm}$) to HCP at 23K. Calculate the parameter a for HCP. (*Hint*: BCC and HCP density are the same.) [10]

Section B - The reciprocal lattice and diffraction

Answer any five questions in this section

- A crystal has n -fold rotation axis if it is invariant to a rotation of $2\pi/n$, $n \neq 0$. Show that $n = 1, 2, \dots, 6$ only. [10]
- The total amplitude of the scattered wave in the direction \bar{k}' for N cells is $F_{\bar{G}} = NS_{\bar{G}}$, where $S_{\bar{G}}$ is the structure factor defined as the integral [10]

$$S_{\bar{G}} = \int_{\text{cell}} n(\bar{r}) e^{-\bar{G} \cdot \bar{r}} dV$$

and $\Delta\bar{k} = \bar{G}$. The lattice vector $\bar{r} = 0$ at one corner. Show that the structure factor for hkl reflections is given by

$$S_{\bar{G}}(hkl) = \sum_j^N f_j e^{-2\pi i(hx_j + ky_j + lz_j)}.$$

9. The electron density (concentration) is given by the Fourier expansion

$$n(\vec{r}) = \sum_{\vec{G}} e^{i\vec{G}\cdot\vec{r}}.$$

Define \vec{G} mathematically and then prove that the definition meets the translational requirement of a periodic crystal, i.e. $n(\vec{r}) = n(\vec{r} + \vec{T})$. [10]

10. Derive the conditions necessary for diffraction in a BCC lattice if the structure factor is given by [10]

$$S_G = \sum_j f_j e^{(-i\vec{G}\cdot\vec{r}_j)}$$

11. The Bragg angle for a certain reflection of a powdered sample of copper is 47.75° at $20^\circ C$, and 46.60° at $1000^\circ C$. Determine the coefficient of linear expansion of copper. [10]

12. A beam of 150 eV electrons is incident on a sample of powdered nickel. If nickel has the FCC structure with $a = 3.25\text{\AA}$, determine the two smallest angles at which diffraction can occur. [10]

Useful constants

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|----------------------|---|
| Planck's constant | $h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$, and $\hbar = h/2\pi$ |
| Avogadro's constant | $6.022 \times 10^{23} \text{ mol}^{-1}$ |
| Electronic charge | $e = 1.6022 \times 10^{-19} \text{ C}$ |
| Electron mass | $m_e = 9.109 \times 10^{-31} \text{ kg}$ |
| Neutron mass | $m_n = 1.675 \times 10^{-27} \text{ kg}$ |
| Boltzmann's constant | $k_B = 1.38 \times 10^{-23} \text{ J/K}$ |