NATIONAL UNIVERSITY OF SINGAPORE

PC4240 Solid State Physics (II)

(Semester II: AY 2014-15)

Time Allowed: 2 Hours

INSTRUCTIONS TO STUDENTS

1. This assessment paper contains **3** questions and comprises **4** printed pages.
2. Students are required to answer all **3** questions.
3. Students should write the answers for each question on a new page.
4. This is a CLOSED BOOK examination.
5. One A4 single side help sheet is allowed for this examination.
6. A book of constants is provided.

1(a) Explain qualitatively why some atoms form paramagnetic and others form diamagnetic materials with reference to the electronic structure of these atoms.

(b) Define the term ferromagnetism, antiferromagnetism and itinerant ferromagnetism. Write down an expression of magnetization of each magnet.

(c) Explain similarities and dissimilarities of the behavior of ferromagnetic order and ferroelectric order.

(d) The static dielectric constant of a NaCl crystal is 5.9, while at optical frequency, the dynamic dielectric constant is 2.34. Explain origins of the difference.

(e) Show that the local field (E_{local}) at a point in an infinite slab of dielectric constant (ε) with a cubic lattice under the macroscopic field (E) is $E_{local} = \frac{1}{3}(\varepsilon + 2)E$. Details of derivation have to be clearly stated.

(f) Describe the behavior of the transition between the normal and superconducting states by considering the temperature dependence of the superconducting gap energy at the Fermi level and the specific heat.

(g) Starting from the tight binding energy expression $\varepsilon_k = -\alpha - \gamma \sum_{nn} \exp(-ik \cdot \rho_m)$, find the band width of a simple cubic lattice with wavevector k along [111] direction.

[42 marks]

2(i) Starting from the Bohr-Sommerfeld quantum condition $\oint d\vec{r} \cdot \vec{p} = (n+\frac{1}{2})h$, show that the flux through the electron orbit (Φ_n) in r-space is quantized as $\Phi_n = (n+\frac{1}{2})(\frac{hc}{e})$, where e is the charge of the electron. [10 marks]

(ii) Given that a line element Δr in the plane normal to B is related to Δk in k-space by $\Delta r = (\frac{\hbar c}{eB})\Delta k$, show that the orbital area in k-space (S_n) is also quantized as $S_n = 2\pi \frac{eB}{\hbar c}(n+\frac{1}{2})$. [6 marks]

(iii) Explain how the expression of S_n in (ii) can be used to measure the Fermi surface. [10 marks]

3 (i) Starting from relations between k vectors of Surface Plasmon Polariton(SPP) at the interface between a metal (m) and a dielectric (d) , $\frac{k_{zm}}{\varepsilon_m}+\frac{k_{zd}}{\varepsilon_d}=0$, where the direction of propagation of the longitudinal wave is x, and the direction perpendicular to the interface is z, show that the dispersion relations of SPP are $k_x^2=(\frac{\omega}{c})^2\frac{\varepsilon_m\varepsilon_d}{\varepsilon_m+\varepsilon_d}$; $k_{zd}^2=(\frac{\omega}{c})^2\frac{\varepsilon_d^{\,2}}{\varepsilon_m+\varepsilon_d}$ and $k_{zm}^2=(\frac{\omega}{c})^2\frac{\varepsilon_m^2}{\varepsilon_m+\varepsilon_d}$. [12 marks]

(ii) Discuss the sign of the real values of ε_m , ε_d and their relative amplitude from the dispersion relation. [4 marks]

(iii) Show that the SPP fields on both sides of the interface are evanescent. [6 marks]

(iv) Write down expressions and sketch dispersion relations of (a) a photon in air (b) a bulk plasmon, and (c) a SPP . Indicate the positions of the bulk plasmon frequency ω_p and surface plasmons frequency ω_{sp} in the same graph. [10 marks]

Ongck

End of Paper