University of KwaZulu-Natal
School of Engineering
Superconductivity I (ENEL4SCH2)

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External Examiner: Professor C. Fourie

Date: October 2025
Time: 2 Hours
Total Marks: 100

Instructions: Answers ALL questions

SECTION A – *Engineering Applications* **30 Marks**

Question 1 – Superconducting Magnetic Energy Storage

(a) Discuss power, energy and efficiency properties of a SMES. Would it be suitable for long-term bulk storage?

(5)

(b) A solenoid/coil has with: *N* turns, *A* cross-sectional area, and l length. Starting with the energy stored in a solenoid is: $U = 1/2\ L\ I^2$, show the energy is stored in the magnetic flux density, B.

(6)

(c) With the help of a sketch, explain how an SMES is energised.

(5)

Question 2 – Superconductor Tapes

(a) With the aid of a diagram, discuss how transport measurements are carried out on a superconducting tape.

(8)

(b) Discuss the effect of contact resistance between a copper bus-bar feeder and a two-tape parallel configuration.

(4)

(c) Why do engineers “stack” superconducting tape?

(2)

SECTION B – *Characteristic Properties and Theory* **35 Marks**

Question 3 – Two Fluid Model

Using the ‘two fluid’ model, explain how a superconductor’s critical current density varies with temperature.

(3)

Question 4 – *BCS Theory*

(a) Use a rudimentary explanation to explain the formation of a ‘Cooper-pair’, and name the parameter that gives a measure of the cooper pair “size”.

(7)

(b) Explain how scientists proved that MgB_2 is a ‘BCS’ superconductor.

(4)

Question 5 – Thermal Conductivity

Explain why the thermal conductivity of a superconductor is smaller in the superconducting state compared to the normal state. Mention one practical application of this property.

(6)

Question 6 – Ginzburg Landau (GL) Theory

(a) What did the GL theory predicate?

(2)

(b) GL theory could have selected the superelectrons density, n_s, as the order parameter, but they choice a wave function, why?

(2)

(c) Using the second GL equation,

$$\underline{J} = curl\ \underline{H} = -\frac{e^*}{m^*}\left[\Psi^2(i\hbar\nabla + e^*\underline{A})\right]$$

derive an expression for the magnetic penetration depth, λ.

(11)

SECTION C – *Superconductor Electronics* **35 marks**

Question 7 – *Junctions*

(a) Discuss an experiment that can be used to determine the energy gap, Δ, of a superconductor. Include a drawing.

(8)

(b) With a V-I curve, explain the working principle of 'Latching Logic', and discuss one advantage over conventional semiconductor-based logic circuits.

(8)

Question 8 – *SQUIDs*

(a) With the help of a sketch, explain the periodic nature of the screening current versus applied magnetic flux in a DC-SQUID.

(7)

(b) Draw the magnetic flux versus voltage relationship for a SQUID.

(4)

(c) How does the flux lock loop circuit connected to a SQUID maintain a stable magnetic flux within the device, and what role does the feedback mechanism play in this process?

(8)

Appendix A – Formulae Sheet

This formulae sheet is not considered complete

$\underline{J} = ne\underline{v}$

$\dot{\underline{B}} = -curl\underline{E}$

$E = \frac{1}{2}\mu_o H_a^2$

$|\Psi|^2 = \frac{-\alpha}{\beta}$

$\xi^2 = \frac{\hbar^2}{2m*|\alpha|}$

$\alpha\Psi + \beta|\Psi|^2\Psi + \frac{1}{2m*}(i\hbar\nabla + e*\underline{A})^2\Psi = 0$

$R = \frac{\rho.L}{t.w}$

$curl\underline{B} = \mu_o\underline{J}$

$div\dot{\underline{B}} = 0$

$B_y(x) = -\frac{\partial A_z}{\partial x}$

$J(x) = J_0 \sin\gamma(x)$

$E_z = -\frac{\partial A_z}{\partial t}$

$curl\underline{H} = \underline{J} + \dot{\underline{D}}$

$curlcurl\dot{\underline{B}} = graddiv\dot{\underline{B}} - \nabla^2\dot{\underline{B}}$

$\omega_0 = \frac{2e}{\hbar}V_0$

$\beta_L = \frac{4I_cR_n}{\pi\Delta V} - 1$

$\beta_L = \frac{2I_cL}{\Phi_0}$

$\beta_c = \frac{2eR_n^2I_oC}{\hbar} \gg 1$

$\gamma = \phi_2 - \phi_1 - \frac{2e}{\hbar}\int_1^2 \overline{A}\cdot\overline{dl}$

$\underline{B}$ = curl $\underline{A}$

$F_s = F_n + \alpha|\Psi|^2 + \frac{\beta}{2}|\Psi|^4$

$\lambda_L = \sqrt{\frac{m}{\mu_0 n_s e^2}}$

$E_M = \frac{1}{2}\mu_o H_a^2$

$F = m\dot{\underline{v}} = e\underline{E}$

$curl\underline{B} = \mu_o\underline{J}$

$\alpha = \frac{m}{\mu_o n e^2}$

$\lambda_L = \sqrt{\alpha} = \sqrt{m/\mu_o n_s e^2}$

$\gamma(x) = \gamma(0) + \frac{2e}{\hbar}B_0[2\lambda + d]x$

$C = \frac{\varepsilon_0\varepsilon_r A}{d}$

$J_0 = \frac{\pi\Delta_0}{2eR_n}$

$V_c = \frac{2\Delta_0}{e}$

$B = \mu_0 N I/l \quad L = \mu_0 N^2 A/l$

More Data: $Y_1Ba_2Cu_3O_{7-\delta}$(Tc) = 92.5K eV = 1.6022×10^{-19} J

$m_e = 9.1095 \times 10^{-31}$ kg ē = 1.6022×10^{-19} C h = 6.6262×10^{-34} J.s

$\hbar = \frac{h}{2\pi} = 1.0546 \times 10^{-34}$ J.s $k_B = 1.3807 \times 10^{-23}$ J/K

$\mu_0 = 4\pi \times 10^{-7}$ H/m $\varepsilon_0 = 8.8542 \times 10^{-12}$ F/m $\Phi_0 = \frac{h}{2e} = 2.0679 \times 10^{-15}$ T.m^2