JUAS 2019 – SC-RF Exam

$\mu = \mu_0 \, \mu_r$
$\mu_0 = 4\pi \cdot 10^{-7}$ Vs/(Am)
$\varepsilon = \varepsilon_0 \, \varepsilon_r$
$\varepsilon_0 = 8.854 \cdot 10^{-12}$ As/(Vm)
$c_0 = 3 \cdot 10^8$ m/s

Name: ___________________________________ Points: ______ of 20
Utilities: JUAS RF Course 2019 lecture script, personal notes,
pocket calculator, ruler, compass, and your brain!
(No cell- or smartphone, no connected device)
Please compute and write your formulas and results clear and readable, if appropriate on a separate sheet of paper. Any unreadable parts are considered wrong.

All multiple choice questions=0.5 point each thus 10 points in total

Q1: what can destroy the superconducting state
A) a magnetic field < than Hc OR a temperature < than Tc?
B) a magnetic field > Hc AND a temperature < than Tc ?
C) a magnetic field <Hc AND a temperature <Tc

Q2: For a homogeneous plane wave impinging orthogonally on a metallic surface the reflection coefficient gamma is
A) very close to zero
B) very close to +1
C) very close to -1

Q3: The surface impedance of a (flat) metallic surface is given by
A) E- tangential/H- tangential
B) H- tangential/E- normal
C) H- normal/E- tangential

Q4: The conductivity sigma of normal conducting metals starts deviating from about constant
A) roughly at 100 GHz
B) never
C in the optical frequency range

Q5: Above the critical temperature the electrical resistivity of a metal or alloy increases
A) linear with temperature
B) proportional to the square root of temperature
C proportional to T^3

Q6: Which statement is correct?
A) only niobium is a type 1 superconductor
B) all elemental superconductors except niobium are of type 1
C) only lead is a type 1 superconductor

Q7: Increasing the temperature from absolute zero In type 2 superconductors we meet
A) first the Abrikosov state
B) first the Meissner state
C) both

Q8: What is the relevance of Hc3 in type 2 superconductors: (select the true answer)

A) between Hc2 and Hc3 we have Abrikosov vortices present
B) the Meissner state is present from H=0 to beyond Hc3
C) Abrikosov vortices occur between Hc1 and Hc2

Q9: In the two fluid model of a superconductor, how does the density of the superconducting electrons (ns) vary with temperature?
A) increasing until 300 K
B) decreasing linear with 1/T
C) decreasing proportional to $1-(T/T_c)^4$

Q10: In a niobium crystal, the London penetration depth at 1 GHz amounts to
A) 90 micrometer
B) 47 micrometer
C) 47 nanometer

Q11: What is the most promising alternative material for superconducting accelerator cavities
A) high-temperature superconductors
B) Nb_3Sn
C) lead

Q12: Where is the world record in terms of electric field strength for superconducting cavities
A) about 60 MV/m with a Q of 4E9
B) around 20 MV/m with a Q of 8E7
C) roughly at 30 MV/m with a Q of 4E10

Q13: Where does the low field Q increase occur
A) between 5 and 15 MV/m
B) below 5 MV/m
C) above 10 MV/m

Q14: What is the velocity of the second sound wave in helium (OST-method)
A) 323 m/s
B) 2500 m/s
C) around 17 m/s

Q15; When using electro-polishing for surface treatment, the surface to be polished is
A) the cathode
B) the anode
C) does not matter

Q16: in an Rf superconductor, how does the additional resistance due to trapped magnetic flux scale with frequency
A) linear
B) quadratic
C) square root

Q17: Multipactor can be a limiting factor for the achievable E-field in superconducting cavities
It occurs

A) only at very high field
B) only at rather low field or moderate field
C) both for small and moderate field strengths

Q18: Field emission can be also a limiting factor for SC-Rf cavities; it occurs
A) only at very high fields
B) over the entire range
C) only at small fields

Q19: What is the thermal conductivity ratio between stainless steel and He II (Helium 2) at 2 K
A) 6 orders of magnitude
B) factor 6
C) 60

Q20: What is the best cure for field emission
A) low temperature baking
B) high-pressure water rising
C) electro-polishing

1. The superconducting "Pillbox" Cavity (5 points total)

You have a superconducting pillbox cavity with a loaded Q and critical coupling of 1E11 at 500 MHz (E010 mode) and a height/diameter ration of 0.5.
What is the diameter?

$$a = \frac{d}{2} = 0.383\lambda \;\Rightarrow\; d = \frac{2 \cdot 0.383 c_0}{f} = 459.3\ mm$$

What is the unloaded Q?

$$Q_0 = 2Q_L = 2 \cdot 10^{11}$$

(2 points)

Determine when, after the cavity had been filled with Rf energy and the generator power is switched off (but generator still connected) the voltage at some output coupler is down to 1/e (e=basis or natural logarithm).
Express the 1/e decay in dB; what is the numerical value in the unloaded case and also the critically coupled case for the 1/e decay time ?

$$\tau_L = \frac{Q_L}{\pi f} = 63.66\ s, \quad \tau_0 = 2\tau_L = 127.3\ s$$

$$\frac{1}{e} = 0.368 \equiv -8.686\ dB$$

Determine the required surface resistance Rs of the cavity material; someone had previously determined its geometry factor G as 250 Ohm (hint: page 61 for the relation between Rs and G)

$$R_s = \frac{G}{Q} = 1.25\ n\Omega$$

(3 points)

2. Resonator and surface impedance (5 points total)

Calculate the BCS surface impedance of niobium at 2 K, using the formula given on one of the slides at 50 MHz and also at 500`MHz.

$$R_s^{BCS} \cong 3 \cdot 10^{-4} \left(\frac{f}{1.5 \cdot 10^9}\right)^2 \frac{e^{-\frac{17.67\ K}{T\ [K]}}}{T} [\Omega]$$

$$\Rightarrow \quad R_s^{BCS}(f = 50\ MHz) = 0.024\ n\Omega, \quad R_s^{BCS}(f = 500\ MHz) = 2.4\ n\Omega$$

Determine also the surface impedance of copper at ambient temperature for the same frequencies.

$$R_s = \sqrt{\frac{\mu_0 \pi f}{\sigma}}$$

$$\Rightarrow \ R_s^{Cu}(f = 50\ MHz) = 1.83\ m\Omega, R_s^{Cu}(f = 500\ MHz) = 5.79\ m\Omega$$

(2 points)

Building a coaxial lambda/2 resonator (shorted at both ends inside) at 100 MHz as a model for a spoke cavity, you would like to determine :

a) The length of the structure (resonator in vacuum)

$$h = \frac{\lambda_0}{2} = \frac{c_0}{2f} = 1.5\ m$$

(1 points)

b) The ratio between the normal and superconducting version in unloaded Q value (no need to calculate the Q values explicitly for each geometry), just assume the same geometry in both cases.

$R_s^{BCS} = 0.097\ n\Omega$

$R_s^{Cu} = 2.59\ m\Omega$

$$\Rightarrow \quad \frac{Q_{NC}}{Q_{SC}} = \frac{R_s^{BCS}}{R_s^{Cu}} = 3.75 \cdot 10^{-8}$$

(2 points)