

STONY BROOK UNIVERSITY
DEPARTMENT OF PHYSICS AND ASTRONOMY

Placement Examination **Electricity and Magnetism**, August 23, 2005

General instructions: Three problems are given. You should do any two. Each problem counts 20 points and the solution should typically take less than 45 minutes. Use one exam book for each problem and label it carefully with your name, the name of the problem's author and the date. You may use a one page help sheet, a calculator, and with the proctors approval a foreign language dictionary. No other materials may be used.

E&M I (Zahed)

Energy loss by classical radiation of an electron in a wire is very small. Indeed, consider an electron in a wire with initial velocity v that is brought to rest because of a collision over a typical atomic distance d .

- a) (8 points) Estimate the ratio R of the energy radiated classically by the electron to its initial kinetic energy.
- b) (8 points) In a good conductor such as Cu, the electrons usually have a Fermi temperature $T_F \sim 8 \times 10^4$ K. Estimate the numerical value of R .
- c) (4 points) What happens to the rest of the electron's kinetic energy?

E&M II (Stephens)

In order to explain certain effects in superconductors, F. London and H. London postulated that in superconductors $\lambda^2 \nabla \times \vec{J} + \vec{H} = 0$, where \vec{J} is a current density, \vec{H} is a magnetic field, and λ is a parameter describing the material. This equation is known as the London's equation. (The equation was introduced in 1935, well before the development of a microscopic theory of superconductivity.)

- a) (6 points) Using London's and Maxwell's equations show that currents are confined to a distance of the order of λ to the surface of a superconductor.
- b) (7 points) On a length scale much larger than λ , what are the boundary conditions of magnetic field at the surface of a superconductor?
- c) (7 points) A slab of superconductor occupies the lower half space, $z < 0$. An infinitely long, thin wire carrying current I is positioned parallel to the x axis, at height $z = d \gg \lambda$ above the superconductor. Find the magnitude and direction of the force per unit length acting on the wire, and determine the surface current density at the superconductor as a function of position.

E&M III (Abanov)

The propagation of the TEM mode in a transmission line in the long wavelength limit can be described by the *telegraph equation*

$$\frac{1}{C} \frac{\partial^2 I}{\partial z^2} - R \frac{\partial I}{\partial t} - L \frac{\partial^2 I}{\partial t^2} = 0$$

where R , L , C are resistance, inductance, and capacitance per unit length of the line respectively. Consider a transmission line (see Figure) consisting of two concentric circular cylinders of metal with air in between ($\epsilon \approx \epsilon_0, \mu \approx \mu_0$). Assume that the frequency is high enough so that the skin depth is small compared to the dimensions of the line.

- (5 points) Calculate the capacitance C and the inductance L per unit length of the transmission line.
- (5 points) Using the telegraph equation and the results of a) find the velocity of the wave in the limit of very small R . How will it change if the air is replaced by a lossless dielectric with dielectric constant ϵ ($\mu \approx \mu_0$)?
- (5 points) Find the solution of the telegraph equation corresponding to a wave of frequency ω moving in the positive z direction.
- (5 points) Show that the transmitted power is attenuated along the line as $P(z) = P_0 e^{-2\gamma z}$ and find the attenuation γ in the limit of small R .

