1. (a) Explain the physical meaning of the following terms:
   (i) *electric susceptibility* and (ii) *displacement current.* (2 %)
   (b) Design an experiment to measure the *dielectric constant* of a dielectric material. (Suppose you only need to know the "static" value of dielectric constant. You need to explain the *principle* of measurements. Try to make your measurement as simple and cheap as possible.). (4 %)

2. (a) Write down the fundamental equations governing the behavior/response/relation of *electromagnetic fields* and *charges* (charge density ρ and current density $\vec{J}$) in a medium of permittivity ε and permeability μ. (4 %)
   (b) From the equations in (a), derive the Kirchhoff's voltage and current laws for electric circuits. (State clearly your assumptions and the "theorems" of vector calculus you might use in the derivations.) (4 %)

3. A charge q (1 C) is placed at a distance d (1 cm) from the center of an isolated conducting shell of inner radius a (2 cm) and outer radius b (3 cm). The conducting shell is also covered uniformly by a dielectric material of dielectric constant 2.0 and thickness 1 cm, as shown in Fig. 1. Find
   (a) the electric field at the center of the sphere, (3 %)
   (b) the force, $\vec{F}$, on the conductor, and (3 %)
   (c) identify all the *charges* (including their locations) in this system, e.g., induced surface charges and volume charges, etc. Please find the density of these charges located in region $r \geq b$. (5 %)
   (d) electric potential at point P (on conductor outer surface). (3 %)

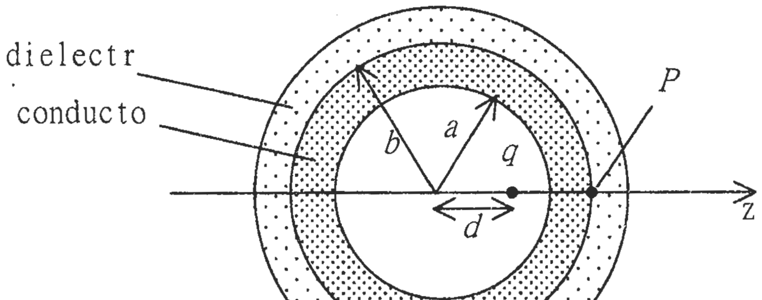

Figure 1

4. A small circular current loop (loop A) of area 1 mm^2 and current 1 A is placed at the center of a 2nd current loop (loop B) formed by 10 turns thin conducting wire with a diameter of 10 cm and current 1 A, as shown in Fig. 2, where the loop A is oriented at an angle of 90° with respect to loop B and the directions of the currents are also shown.
   (a) What's the torque on loop A? (Assuming the magnetic due to current in loop B is uniform near the center, i.e., $\vec{B} = \vec{B}(\text{center})$.) (3 %)
   (b) What's final orientation of the loop A if it is allowed to rotate freely with its center fixed (loop B is not allowed to move)? (2 %)
   (c) If loop A is oriented in the same direction with loop B, find the mutual inductance between the two loops. (3 %)
   (d) If now the current in loop B is decreased from 1 A to 0 A, how much energy does it take to keep the current in loop A constant against the induced mutual *emf* in loop A ? (4 %)

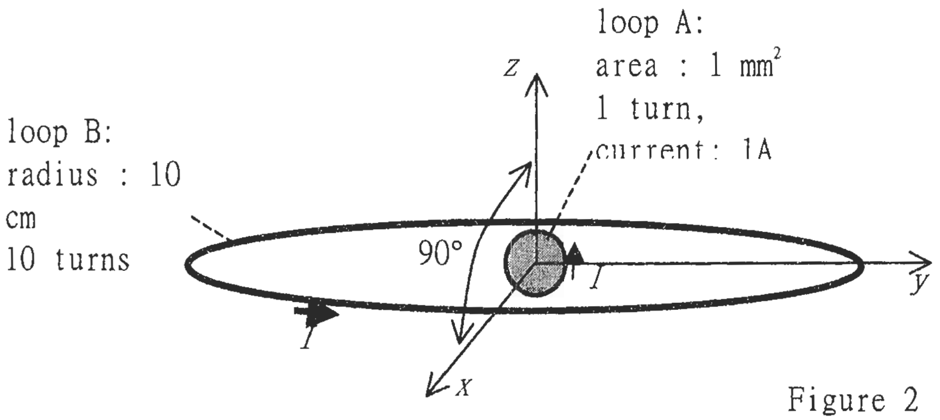

Figure 2

5. Let us consider an electromagnetic plane wave incident from a medium into another.
   (a) Please prove that the components of the incident, reflected and transmitted waves parallel to the interface are equal. (4%)
   (b) For the transmitted wave, we find the normal component of the transmitted wave to be pure imaginary. Please prove that the time averaged Poynting vector along the formal, i.e., the normal, direction vanishes. (6%)
   (c) (Continue) Is there anything wrong we have electromagnetic waves with zero net power flow in the second transmitted region? Please explain the physics. (2%)

6. Let us consider an electromagnetic plane wave incident from a medium into another again. For the TM polarized wave, there exists an angle, called the Brewster angle, giving zero reflection. Using basic physics (but no mathematic equation), please clearly discuss this. (4%)

7. We use the equivalent circuit model to analyze signal propagation in transmission lines where the spatial variations of the signal in these pure conductors are seen. We associate distributed inductors along the signal propagating direction and associate distributed capacitors in the transverse direction. Can we interchange these inductors and capacitors though we still have voltage differences between two terminals of an inductor and of a capacitor in circuitry, concerned? Please answer this question based on the fundamental electromagnetism. (10%)

8. You learned electromagnetic waves guided by rectangular metallic waveguides.
   (a) The lowest order mode is the most desirable. Please explain it. (3%)
   (b) For any a physical waveguide of a finite size, these is a cut-off frequency if it isn't circular. Can we achieve zero cut-off frequency, i.e., all frequencies allowed in propagation if we make a metallic waveguide with its cross section to be circular? Please prove this. (7%)

9. When we design linear radiating antennas, their lengths aren't arbitrarily set. Please explain this. (4%)

10. The Smith chart is a very useful tool in RF circuit design. Consider a transmission line of characteristic impedance 50 Ω is terminated by a load impedance $Z_L = (15 - j20)\ \Omega$. Determined the following quantities by using the Smith chart as shown. You have to use the Smith chart to find the answers. No credits will be given if you use the equations instead. (Although the Smith chart provide here is not complete, still all the relevant values needed to find the answer are shown on the chart. Note that the dashed line indicates the normalized resistance *r* and reactance *x* of the corresponding point.)

(a) Reflection coefficient Γ at the load. (4%)
(b) SWR (standing-wave ratio) on the line. (3%)
(c) Distance of the first voltage minimum of the standing-wave pattern from the load. (3%)
(d) Line impedance at d = 0.05 λ from the load. (3%)
(e) Line admittance at d = 0.05 λ from the load. (3%)
(g) Location nearest to the load at which the real part of the line admittance is equal to the line characteristic admittance. (4%)