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Electrodynamics, Physics 323 Spring 2005

**First midterm** Instructor: David Cobden 8.20 am, April 25, 2005

You have 60 minutes. End on the buzzer at 9.20. Answer all questions. You are strongly recommended to read through all the questions before you begin. Write your name on every page and your ID on the first page. Watch the blackboard for corrections or clarifications during the exam. In this exam you are allowed **no books, no note sheets, and no calculators !** 

Write all your working on these question sheets. You will get credit for it. It is important to show your calculation or derivation. You usually won't get full marks just for stating the correct answer.

Do not turn this page until the buzzer goes.



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I. Consider the following equation for the time-varying electric field in a material:

$$\nabla^2 \mathbf{E} = \mathbf{m} \mathbf{e} \, \frac{\partial^2 \mathbf{E}}{\partial t^2} + \mathbf{m} \mathbf{s} \, \frac{\partial \mathbf{E}}{\partial t},\tag{1}$$

where  $\mathbf{m}, \mathbf{e}$  and  $\mathbf{s}$  are scalars or second-rank tensors.

1. [24] Indicate whether each of the following statements about Eq. (1) is true or false: (write T or F)

- a. It is valid only in metallic (reasonably conducting) materials.
- b. It is valid only at frequencies between some characteristic lower and upper limits.
- c. It is valid only in linear materials.
- d. It is valid only in isotropic materials.
- e. It is valid only if the net space charge r(r) is constant or zero.
- f. It is not valid in a dilute plasma.
- g. At finite frequency w the distinction between s and e is arbitrary.
- h. The magnetic field obeys exactly the same equation.

2. [6] Find the general dispersion relation k(w) for a monochromatic plane wave that obeys this equation, indicating all possible origins of the frequency dependence of k.

3. [10] Using one of Maxwell's equations, find an equation relating the magnetic and electric fields for the plane wave, and deduce the impedance Z = E/H of the material in terms of the parameters in Eq. (1).

4. [10] For a dielectric ( $\sigma = 0$ ), show that the wave phase velocity at high frequencies is  $v_{ph} \approx c/\text{Re}[\boldsymbol{e}_r]$ .

5. [5] For a conductor, Eq. (1) implies a characteristic timescale  $\tau$  for motion (relaxation) of free charge. What is  $\tau$ , in terms of the parameters in the equation?

6. [10] Show that the phase velocity of monochromatic plane waves in a conductor with  $\varepsilon_r = 1 = \mathbf{m}$  in the limit  $\mathbf{wt} \ll 1$  is  $(2\mathbf{wt})^{1/2}c$ .

7. [10] Show that information is carried at much less that the speed of light by such waves.

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8. [10] The conductivity of silver is about  $8 \times 10^7 \ \Omega^{-1} \text{m}^{-1}$ . *Estimate* the minimum thickness of the silver film needed on the back of a mirror. (Take  $\mu_0 \approx 10^{-6} \text{ Hm}^{-1}$ ).

II. A transmission line consists of two coaxial conductors. The space between them, which occupies the region a < r < b where *r* is the distance from the axis, is filled with a linear dielectric of dielectric constant  $e_r$  and negligible magnetic susceptibility.

9. [5] State the dispersion relation for a TEM mode travelling along the line.

10. [20] Find the impedance Z = V/I for the TEM mode.