Electrodynamics Exam

Prof. T.E. Coan
Prof. R Scalise
Prof. R. Vega
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Printed Name ______________________________

Printed email address ______________________________

DIRECTIONS:

0. If we cannot read it, we cannot grade it.

1. **BOX YOUR FINAL ANSWERS**

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3. Do 2 out of 3 "L" problems. Do 2 out of 4 "S" problems.
4. Paginate all pages. Label the problem number clearly on **EACH** sheet.
5. **DO NOT** staple pages together so we can bulk scan efficiently.
6. Good luck!

S1 10 pts. Two protons are traveling parallel to one another a (transverse) distance r apart, with the same speed βc as measured in the lab frame.

a) What is the magnitude of the electric force of repulsion F_{E} as measured in the lab frame?

b) What is the magnitude of the lorentz magnetic force F_{B} acting on one of the protons (as measured in the lab frame)? What direction does this lorentz force point? A sketch may be useful.

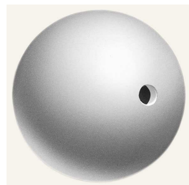
S2 10 pts. An elastically bound proton of mass m vibrates in simple harmonic motion with angular frequency ω and amplitude A. You can assume its motion is non-relativistic.

a) What is the *average* rate of energy loss P by radiation? Box that answer.

b) If no energy is supplied to make up the loss, how long τ will it take for the oscillator energy to drop to $1/e$ of its original value? Box the answer.

S3 10 pts. Consider an interstellar grain, roughly spherical in shape with a radius $r = 3 \cdot 10^{-7}\,\mathrm{m}$ that has acquired a negative charge such that its potential is $-0.15\,\mathrm{V}$. You can take its mass m to be $m = 10^{-16}\,\mathrm{kg}$. Suppose the grain is moving quite freely, with speed $v \ll c$, in a plane perpendicular to the interstellar magnetic field, which in the relevant region has a magnitude of $3 \cdot 10^{-10}\,\mathrm{T}$. How many *years* T will it take to complete a circular orbit? Box your final answer.

S4 10 pts. A uniformly positively charged insulating spherical shell has a surface charge density σ. A very small hole is cut in the shell. Find the electric field $\mathbf{E}$ at the center of the hole and be sure to include its direction! Box that answer.

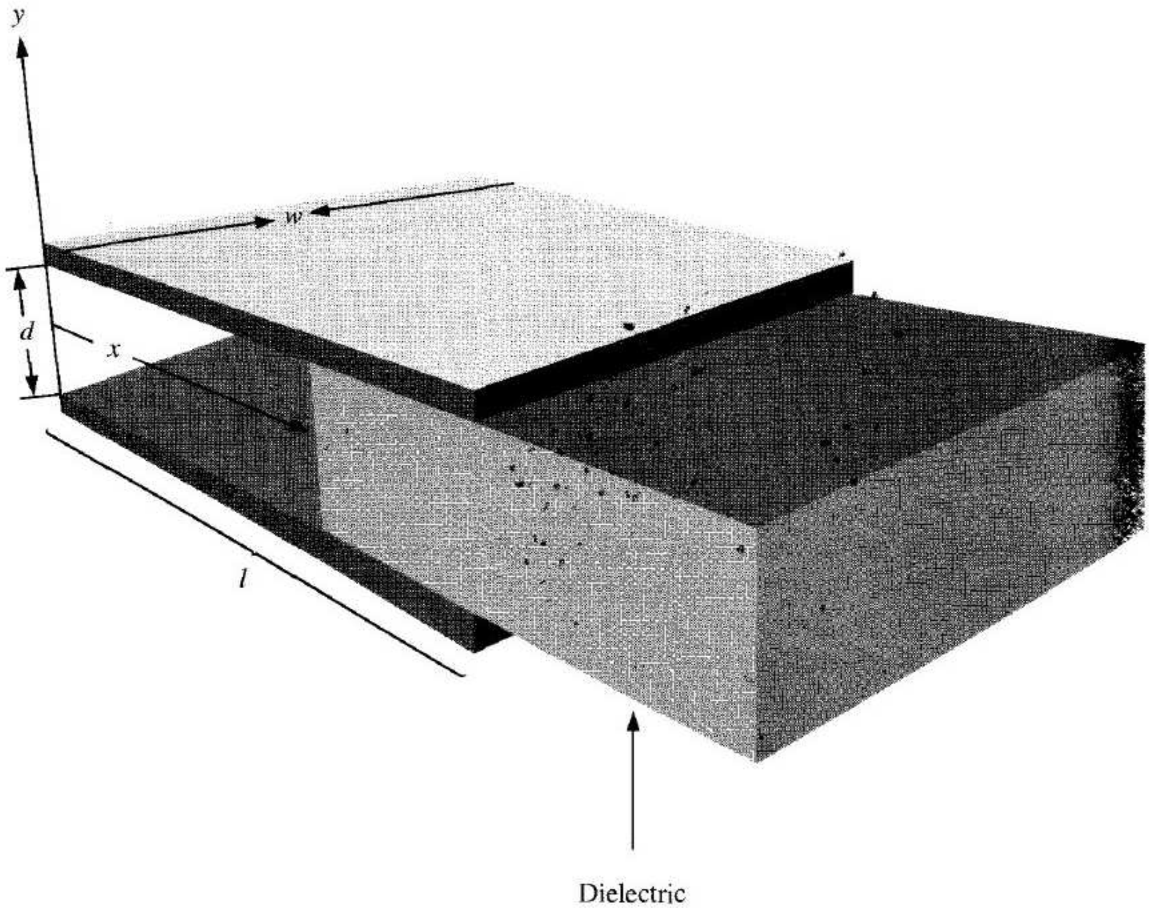


L1 20 pts. The xy-plane is insulating and carries a uniform surface charge density σ, except for a circular hole of radius R which is cut out of the plane. Take the origin at the center of the hole.

a) 10 pts What is the volume charge density $\rho(\mathbf{r})$ in cylindrical polar coordinates?

b) 10 pts What is the electric field $\mathbf{E}_z$ along the z-axis?

L2 20 pts. Calculate the force on a dielectric slab partially inserted between the plates of an isolated parallel plate capacitor. The slab's dielectric constant is κ and the charges on the plates are $\pm Q$.



a) 5 pts Is the slab drawn into the capacitor or pushed out of it?

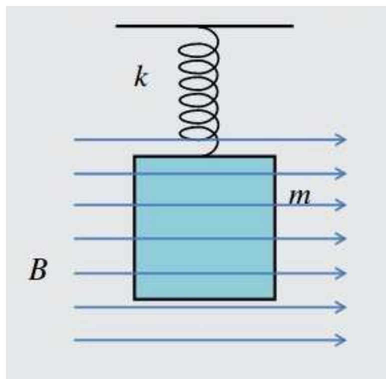
b) 5 pts With the slab inserted as shown, what is the capacitance C?

c) 5 pts What is the energy E stored in the capacitor shown?

d) 5 pts What is the relation between force and energy for this situation? Use it to calculate the force on the slab.

L3 20 pts. You are used to constant forces (like weight near Earth's surface) and forces proportional to the object's velocity (like viscous drag). You may not have seen a force proportional to the object's acceleration; forces like this look like they change the object's mass to an effective mass. In this problem you will explore such a force.

A thin copper plate of mass m has a shape of a square with a side b and thickness d. The plate is suspended on a vertical spring with a force constant k in a uniform horizontal magnetic field B parallel to the plane of the plate. Find the period of the small-amplitude vertical oscillations of the plate. Do this in steps as outlined below.



a) 5 pts When the plate is moving downward, what sign of electric charge accumulates on the front face?

b) 5 pts Treating the plate with opposite sign charges on its front and back faces as a capacitor, what is the potential energy U stored in this capacitor in terms of the plate dimensions, the magnetic field, and the instantaneous plate speed v?

c) 5 pts The force exerted on the moving plate by the magnetic field is $F_B = -\frac{dU}{dy}$. Show that this force is proportional to the plate's acceleration a.

d) 5 pts Finally, use Newton's second law in the vertical direction to write a differential equation from which by inspection you can find the period of vertical oscillations in the field B.