OFFICE MEMORANDUM ◇ STAR LABORATORY

January 30. 2002

To: Diane Shankle

From: Tony Fraser-Smith

Subject: Ph.D. Quals Question, 2002

Penetration of Low-Frequency Electromagnetic Fields

The student is presented with three thin metal plates and asked about their electric and magnetic properties. Two of the plates are aluminum, with one about four times the thickness of the other. The other plate is steel; it is about the same thickness as the thinner aluminum plate. The student is very briefly asked about electrical conductivity σ, electrical permittivity ϵ ($= \epsilon_o$ in free space), and magnetic permeability μ ($= \mu_0$ in free space). Inevitably they can write the formula for skin depth $\delta = \sqrt{2/\omega\mu\sigma}$, i.e., the distance over which an electomagnetic wave of angular frequency ω will propagate through a conductor before its amplitude declines to $1/e$ of its initial value.

A strong horseshoe magnet is produced; the steel keeper is removed, and placed on the desk. The student is asked to check the metal plates to see if they are magnetic (the steel plate is) and then asked if the magnet will attract the keeper through the three different plates. In the subsequent discussion involving skin depth (δ) the student will need to recognize that ω is very small whereas σ is quite large for metals and μ is also quite large for the steel plate. Having discussed the situation and hopefully with the student having demonstrated some ability to think as an engineer, we carry out a test and find that the keeper is attracted in all cases, but the strength of attraction decreases as follows: (1) thin aluminum plate, strongest; (2) thick aluminum plate; (3) steel plate (weakest). This is exactly what would be expected if the skin depth was a major factor in the attractive force.

The student is now asked if there is any other reason for the strength of attraction between the magnet and its keeper being weaker when the thicker aluminum sheet is used. At this stage the student should realize that the distance between the magnet and the keeper is greater for the thicker sheet and that as a result the attraction could be weaker for that reason alone. A this time he/she might question the skin depth argument, but the situation can be rescued by the student comparing the attractive forces when the thin aluminum and the steel plates are used. Since they are the same thickness the different compositions as clearly an important factor.

Finally, the magnet is moved around on one side of the thin aluminum plate and it is seen how the keeper tracks the motion on the other side of the plate. The point here is that there has to be a component of attractive force parallel to the surface of the plate for the keeper to move and this requires the magnet to be offset relative to the keeper.