**Transformed E&M I materials**

**Gauss’ Law, divergence and curl of E**

**(Griffiths Chapter 2)**

**STUDENT DIFFICULTIES**

**Using Gauss’ Law (\*)**

* A surprising number of students still struggle with the mechanics of applying Gauss’ Law. They may forget to include the (EA) term from both sides of a Gaussian pillbox, for example, where E is not zero on one side. They are often off by a factor of “2” in pillbox problems. Some students attempted to use Gaussian pillboxes to solve for E due to a cube with a charge density that depended on z, not recognizing that there would be a nonzero (and varying) E field inside the cube. In another problem, many students calculate that the *flux* of E is zero in a region, and thus wrongly conclude that E itself is zero.
  + Students are often unclear about the distinction between flux and electric field, sometimes using the words interchangeably.
* Students often have difficulty articulating the symmetry arguments necessary to determine when Gauss’ law is applicable. They struggle particularly with geometric arguments. Griffiths uses a geometric argument only once and as such students often use only superposition arguments which are significantly more challenging in certain situations.

**Applicability of Gauss’ Law (\*\*)**

* Most students are familiar with Gauss’ Law from previous courses. However, they still have trouble knowing when it’s useful. However, once presented with alternative ways of solving for E or V (such as the integral forms) some lose sight of when Gauss’ Law is applicable. At this point in the course, most students said they struggled most with knowing how to set up a problem. We stressed that Gauss’ law is always *true* but not always *useful* and this seemed to be helpful to students, who scored better than traditionally-taught students on an exam question on when to apply Gauss’ Law. On the homework and exams, we observed students calculate E using Coulomb’s Law when Gauss’ Law was applicable.
* In particular, students (especially in the Traditional course) hadn’t seemed to grasp that Gauss’ Law is only useful in cases of high symmetry. In many cases, they gained this understanding over the course of the semester, though many still had trouble defining just what type of “symmetry” was necessary (is a cube symmetric in the right way?) When asked how to solve for the potential of a point charge outside of a conducting sphere, many chose Gauss’ Law, though they recognized that the sphere would polarize.
  + Even some of these upper-division students still seemed to use gauss’ law by rote, just solving EA=Q/ϵ without considering symmetry or visualizing the field.
  + It is likely that students know you cannot pull a non-constant function out of an integral as they have completed a multivariable calculus course however they may not apply this knowledge in the context of a Gauss’ law problem.

**Integral and differential form of Gauss’ Law / Divergence Theorem (\*\*)**

* Students have difficulty translating between integral and differential forms of Gauss’ Law, and struggle with a physical conception of the divergence theorem. A student looking at  do not readily recognize this as the familiar Gauss’ Law (just in a different form) in an interview setting. By the end of the course, they are better able to do this, but it seems that they may have simply memorized the two forms of the equations (eg.,  and  ).
* Several students translated between those two forms by knowing that *ρ* needed to be changed to *Q*, and so both sides must be integrated by volume. This does eventually invoke the Divergence theorem (because the integral of the divergence of E must be changed to the closed integral of the flux of E). However, students generally do not invoke the Divergence theorem as a method of translating a divergence to an integral, rather it’s a “trick” to make the two sides of the above equations match. Using a more familiar physical example (like water flow) to talk about the divergence theorem may be useful.
  + Student difficulties here may relate to problems visualizing the divergence in a meaningful way. See the math difficulties resource document for more on student difficulties with divergence.