**Transformed E&M I materials**

**Divergence and Curl of B**

**(Ampere’s Law)**

**(Griffiths Chapter 5)**

**STUDENT DIFFICULTIES**

**Amperian loops (\*)**

* Drawing Amperian loops is a little difficult. It seems hard for students to visualize where B will be constant along a loop (suggesting a particular geometry for the loop), as well as where to place the loop once they have figured out the right geometry. Ie., should a rectangular loop be placed symmetrically about the boundary, or have one side lie along the boundary? Giving students challenging (non-standard) Ampere’s Law problems seems to help them struggle with it. Those in the Transformed course seemed more comfortable.

**Boundary conditions on B (\*\*\*)**

* Even the best students have great difficulty applying Ampere’s Law (and the fact that ) to generate the boundary conditions on B. They do not think, for example, to draw a loop around a surface current and use Ampere’s Law around that loop. This is often done *for* them and so when asked to *generate* the boundary conditions, they don’t know where to start.
* Even though are familiar with using Gauss’ Law to generate the conditions on the perpendicular part of E, they do not generalize this result to be able to derive the conditions on the perpendicular component of B using . At least some think that Stokes’ Theorem is for B, and Divergence Theorem/Gauss’ Law is only used for E. This is true even of many of the best students.
* As with the boundary conditions for E, students also struggle with whether there should be a negative in the final equation () because they interpret *B||* as a vector instead of a component, and so do not include the negative sign where appropriate.
* I strongly recommend a whiteboard activity where they are asked to derive the parallel and perpendicular boundary conditions on B.

**Integral and differential forms (\*\*\*)**

* Students struggle with understanding the equivalence of the integral and differential form of Ampere’s Law using Stokes’ Law. This is a major and persistent difficulty.
* I saw several students translate from the differential form by looking at the right hand side of the differential equation (i.e. “I”) and recognizing you need to integrate over volume to get the right hand side of the integral form (i.e., “J”). They invoked Stokes’ along the way, but it was not the driving force of the calculation. Their shaky understanding of Stokes’ was evident when they were asked to translate  to integral form. Without the right-hand side as a guide, they were stuck as to whether to do the integral over volume or area. They did not easily recognize that if a vector field has no curl, then the integral of that field around a closed loop is zero.

**Stokes’ Theorem (\*\*\*)**

* Students struggle with understanding and using Stokes’ theorem. A physical interpretation of Stokes’ theorem is useful. However, many students will draw a closed loop and realize that the circles inside the loop add up to something around the whole loop, but they are not clear on *what* is being added up. Are they bound current loops representing atoms, for example? Students have much more difficulty *visualizing* Stokes’ theorem than the divergence theorem.
* Students can understand a physical interpretation of Stokes’ theorem, but making the connection to understand how this applies to Ampere’s Law is difficult.

**Curl of B**

* If students have difficulty with curl (which most do), this is where it will show up. Students struggle with the idea that if there were magnetic charge, then B would have a divergence like E. When checking to see if a B field could exist, many check for curl but do not check for divergence.

**Magnetic monopoles**

* When considering the hypothetical existence of magnetic monopoles, students do not automatically assume that monopoles would create a nonzero . They don’t know what a monopole would look like (our best illustration is of an isolated north pole), and don’t assume the B field would be radial. One student was concerned that two monopoles with radial B fields can’t be easily combined to give a circumferential B field.