01. Concepts and Principles

Creating Electrical Energy

When electric charges move, their electric fields vary. In the previous two chapters we considered moving electric charges as the source of magnetic fields, but we could just as easily have considered the variation in the electric field as the source of the magnetic field. This leads to an interesting question: If varying electric fields can create magnetic fields, can varying magnetic fields create electric fields? The answer is yes, and this process, termed electromagnetic induction, is at the heart of almost all electrical power generation worldwide. In addition to incredible technological importance, electromagnetic induction hints at a deep inter-relationship and symmetry between electric and magnetic fields that will be explored more fully in later chapters.

Imagine a region of space with a magnetic field. Surrounding a portion of this region is a hypothetical closed path. (Often, a real loop of wire will be the closed path of interest, but induction occurs whether or not a real wire loop is present.)

pic 1

First, let me define magnetic flux. In analogy to electric flux, introduced in conjunction with Gauss' Law, magnetic flux is defined to be:

pic 2

This equation involves the vector dot product between the magnetic field and an infinitesimally small area within the area bounded by the closed path. This dot product between magnetic field and area often visualized as the amount of field that "passes through" the little piece of area. The integral simply tells us to add up all of these infinitesimal magnetic fluxes to get the total flux through the area enclosed by the path.
Second, let me define \textit{emf}. (Actually, let me apologize. Emf \textit{used} to stand for electromotive force, even though it is not a force. In light of this misleading name, emf now, officially, stands for emf. It's not short for anything. I'm not making this up.) Emf is the name for the electrical energy per unit charge created by changing magnetic flux. In general, any process that generates electrical energy "creates" emf. In addition to changing magnetic flux, chemical batteries and some solar cells create emf. Mathematically, emf is defined by integrating the electric field around the closed path described above:

![Pic 3](image)

(Don't worry, you will never actually calculate this integral.) All you need to know is that emf is the energy created per unit charge. The units of emf, joules per coulomb, are given the name \textit{volts} (V). In crude language, an emf is a "voltage".

Let's put this all together. The central relationship describing electromagnetic induction, termed \textit{Faraday's Law}, claims that:

![Pic 4](image)

where

- \(e\) is the emf induced (the voltage created) in the closed path,
- \(F\) is the magnetic flux that passes through the closed path,
- and the negative sign indicates that the emf's direction in the closed path is to \textit{oppose the change in magnetic flux}. (If the closed path is a real loop of wire, the emf will drive an induced current whose direction is such that the magnetic field produced by this induced current is opposite to the change in magnetic field that produces the induced current. Crystal clear?)

\begin{align*}
\left(\frac{\Delta \Phi}{\Delta t}\right) & = \int_{C} E \cdot dl \\
(\text{Don't worry, you will never actually calculate this integral.) All you need to know is that emf is the energy created per unit charge. The units of emf, joules per coulomb, are given the name volts (V). In crude language, an emf is a "voltage".)
\end{align*}

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