MATERION

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TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

DIELECTRIC PROPERTIES OF ELECTRICAL INSULATORS

All Charged Up!
– A brief discussion on the properties of dielectric insulators.

- **Electric Polarization**
- **Dielectric**
- **Dipoles**
- **Polar**
- **Non-Polar**
- **Permittivity**
- **Relative Permittivity**
- **Dielectric Constant**

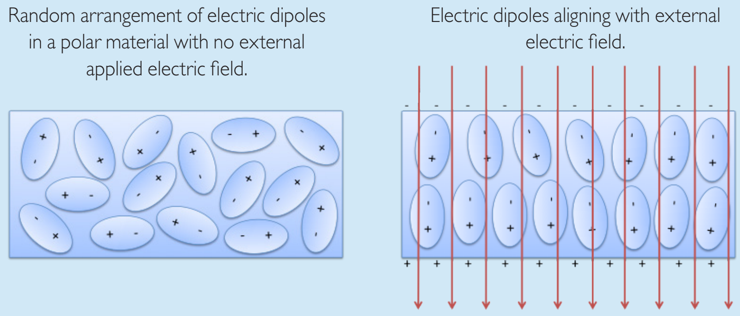
The next issue of Technical Tidbits will discuss electrical losses due to polarization.

This issue is a departure from the typical topics of Technical Tidbits, since we will be talking about properties of electrical insulators instead of metals. It would be hard to talk about electrical and thermal properties without mentioning how such properties differ in non-metals. Furthermore, many electrical and electronic connectors depend on dielectric materials for proper operation.

Simply put, if an electrical insulator is electrically **polarizable**, then the material is called a **dielectric**. The kindergarten definition of an insulator is a material that does not conduct electricity. Such a definition would imply infinite resistivity, which (unfortunately) does not actually exist. So, the better definition of an electrical insulator is a material with very high electrical resistivity, which does not readily conduct electricity. The italicized terms are vague and imprecise, which would seem to suit marketing better than engineering. Still, specific values of resistivity that might represent cutoff points between insulators, semiconductors and conductors will likely depend on the particular application (not to mention the applied voltage), so the fuzzy definition will have to do.

Anyway, a material is electrically polarizable if it contains electric **dipoles** that can align themselves with an applied electric field. A dipole is essentially a particle or molecule that has equal and opposite charges on each end. Substances made of molecules that have permanent dipoles (that is, each molecule has a permanent positive charge one side and a permanent negative charge on the other side) are called **polar** materials. Other polar materials may have permanently charged ions (both positive and negative) inside are free to travel through the substance. When external electric fields are applied, the dipoles or ionic charges will orient themselves to be aligned with such fields (Figure 1).

If the atoms and molecules that make up a material do not have permanent separation of positive and negative charge (the center of positive charge and the center of negative charge are the same), then they are called **non-polar** materials. Some non-polar materials, however, can be polarized by an applied electric field, as each atom's electron clouds tends to distort towards the positive side of the electric field, leaving that end with a negative charge and the opposite end with a positive charge. Such non-polar materials would also be considered dielectrics.



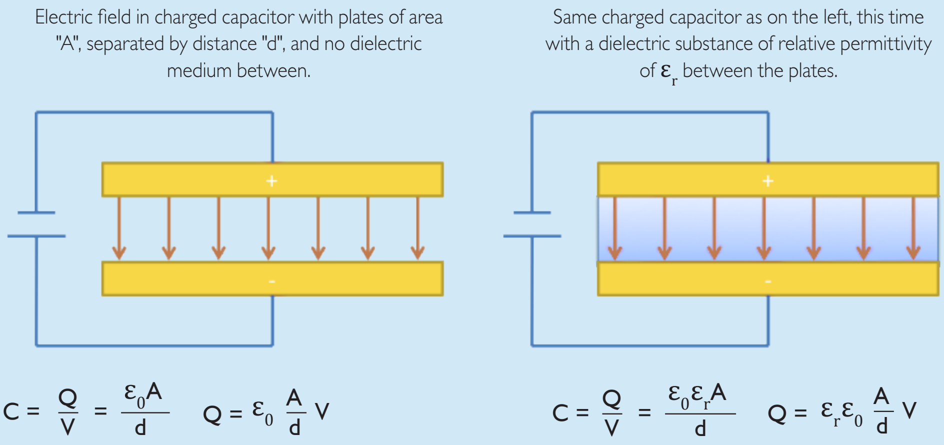
Random arrangement of electric dipoles in a polar material with no external applied electric field.

Electric dipoles aligning with external electric field.

Figure 1. Schematic Representation of Polarization of a Dielectric Material.
Note that the surfaces of the dielectric become charged when the external field is applied. In a non-polar dielectric, individual atoms will behave in this manner, as their electron clouds will distort so that one side of each atom will be more negatively charged and the other side will be more positively charged.

DIELECTRIC CONSTANT (CONTINUED)

When a dielectric material is placed between the plates of a capacitor, its dipoles align with the electric field as shown in Figure 1. This effectively allows additional charge to accumulate on the plates. Looking at the formulas shown in Figure 2, you can see that the amount of charge as a function of voltage depends upon the plate geometry and a proportionality constant known as the **permittivity constant (ε_0).** In air or in a vacuum, the permittivity constant is equal to 8.854 x 10^{-12} C/Vm or F/m.



$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d} \qquad Q = \varepsilon_0 \frac{A}{d} V$$

$$C = \frac{Q}{V} = \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad Q = \varepsilon_r \varepsilon_0 \frac{A}{d} V$$

Figure 2. Representation of a capacitor with and without a dielectric.
For simplicity, only the electric field lines outside the plates are omitted. Since the dielectric effectively increases the amount of charge that the capacitor can hold at a given voltage, the relative permittivity (or dielectric constant) is always greater than 1.

By adding the dielectric material, permittivity increases. The amount that the permittivity increases is known as the **relative permittivity (ε_r),** or **dielectric constant.** Since dielectric substances increase permittivity, the dielectric constant will always be greater than 1. Note, however, that there is no good value for the dielectric constant of metals or conductors. Such materials would essentially have very high or infinite relative permittivity, with an effective dielectric strength of 0 (more on this in later editions of Technical Tidbits). If you put a conductive metal between the plates of a capacitor, then you no longer have a capacitor, you now have a resistor.

Next month we will have a more in depth discussion on polarization and how it leads to losses in electrical performance.

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