Polymer as an Insulating Material

The majority of polymers are insulators, meaning these materials prevent the flow of an electrical current (due to an unavailability of free electrons to create conductivity). Such a material is called a **dielectric *or an* electrical insulator.**

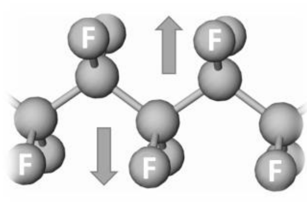
These polymers are commonly used in electrical applications as insulators due to their exceptional electrical, mechanical, chemical and thermal properties. Polymer-based electric insulators exhibit high dielectric strength, high resistivity, low dielectric loss, and adequate mechanical properties.

Polarization of Polymer

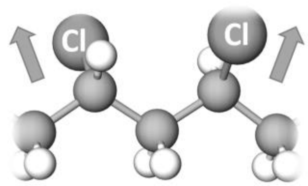
The majority of polymers have polarized covalent bonds, that is, **the electrons are drawn closer to the more electronegative atoms**. These dipoles will orient themselves to align up with the electrical field, very similar to a compass needle that attempts to align up with the earth's magnetic field.

The dielectric properties of polymeric materials depend on the chemical composition and structure of the polymer. **Non-polar polymers** with a symmetrical structure and covalent bonds are typically the best electrical insulators. Since there are no dipoles present in the repeat units, an applied field cannot cause any dipoles to align in field direction which would weaken the electrical field, and thus increase the dielectric constant. The electrical field, however, can push the electrons slightly in the directions of the positive electrode which creates some polarization. This effect is known ***as* electronic polarization**. Since this effect is nearly instantaneous, the frequency of the electrical field will not much affect this form of polarization. Or in other words, the dielectric constant of non-polar materials such as PE, PP, PS, PIB, and PTFE (and many other symmetric fluoropolymers) is nearly independent of the frequency. These materials also have very high resistivity.

The majority of polymers have polarized covalent bonds, that is, the electrons are drawn closer to the more electronegative atoms. These dipoles will orient themselves to align up with the electrical field and hence it results much stronger dipole polarization and a higher relative permeability (dielectric constant) and a lower resistivity compared to non-polar polymers. The effect is known as **orientational *or* dipole polarization**.



PTFE



PVC

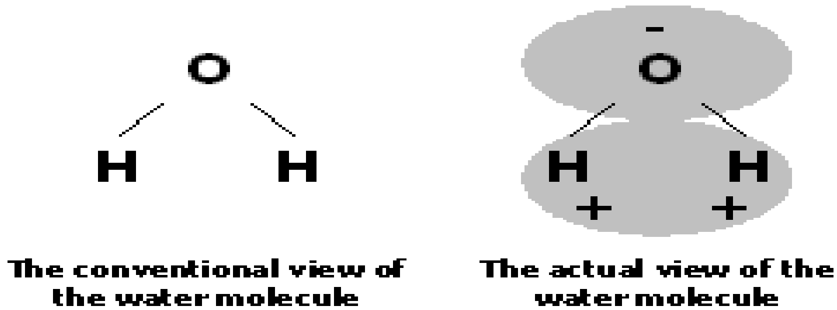
The orientational polarization depends on the temperature and field frequency whereas the electronic polarization is more or less independent of the frequency and shows a much weaker dependency on the temperature (instantaneous polarization of non-polar plastics).

Both the orientational polarization and electronic polarization depends on the chemical composition of the polymer repeat units. For example, aromatic rings, sulfur, bromine and phenol increase the relative permittivity because they are highly polarizable. The same is true for the π bonds in aromatic rings. They are more polarizable than σ bonds, and thus also increase the relative permittivity. Very electronegative elements such as fluorine have an even stronger effect on the dielectric constant. However, this is only true if the dipole moments in the repeat units do not balance each other, as it is the case in PTFE whereas the C-F bonds in the repeat units of polyvinyl fluoride (PVF) can all align parallel to each other and to the electric field which greatly increases the polarization. This additive effect and the strong dipole moment of the C-F bonds explain the very high dielectric constant of PVF ($\varepsilon \approx 8$) whereas PTFE has a rather small dielectric constant ($\varepsilon \approx 2$).

Polar and Non-Polar Polymers

Not all polymers behave the same when subjected to voltage and plastics can be classified as ‘polar’ or ‘non-polar’ to describe their variations in behavior.

The **polar plastics** do not have a fully covalent bond and there is a slight imbalance in the electronic charge of the molecule. A simple example of this type of behavior would be that of the water molecule (H_2O). The conventional representation of the molecule is that shown at right. The two hydrogen atoms are attached to the oxygen atom and the overall molecule has no charge.



In reality, the electrons tend to be around the oxygen atom more than around the hydrogen atoms and this gives the oxygen a slightly negative charge and the hydrogen atoms a slightly positive charge. This is shown in the diagram at right where the grey areas show where the electrons are more often found. The overall water molecule is neutral and does not carry a charge but the imbalance of the electrons creates a 'polar' molecule. This 'polar dipole' will move in the presence of an electric field and attempt to line up with the electric field in much the same way as a compass needle attempts to line up with the earth's magnetic field.

In polar plastics, dipoles are created by an imbalance in the distribution of electrons and in the presence of an electric field the dipoles will attempt to move to align with the field. This will create 'dipole polarization' of the material and because movement of the dipoles is involved there is a time element to the movement.

Examples of polar plastics are PMMA, PVC, PA (Nylon), PC and these materials tend to be only moderately good as insulators.

The **non-polar plastics** are truly covalent and generally have symmetrical molecules. In these materials there are no polar dipoles present and the application of an electric field does not try to align any dipoles. The electric field does, however, move the electrons slightly in the direction of the electric field to create 'electron polarization', in this case the only movement is that of electrons and this is effectively instantaneous.

Examples of non-polar plastics are PTFE (and many other fluoropolymers), PE, PP and PS and these materials tend to have high resistivity and low dielectric constants.

KEYPOINTS

Insulators also called dielectrics are made of materials that prevent the flow of an electrical current.

Dielectric Constant

The dielectric constant or relative permittivity describes how much the electrical field intensity decreases when the dielectric medium is placed between two electrodes.

Electronic Polarization

The electrical field pushes the electrons of the local electronic charge clouds that surround each nucleus slightly in the directions of the positive electrode.

Dipole Polarization

The polarized covalent bonds (permanent dipoles) orient themselves to align up with the external electrical field.

- The dipole polarization depends on the temperature and field frequency whereas the electronic polarization is more or less independent of the frequency and temperature.
- Since the electronic polarization is virtually instantaneous, it is nearly in phase with the changing electric field whereas dipole polarization is out of phase at high frequencies.
- Both the dipole polarization and electronic polarization depend on the chemical composition of the polymer repeat units.
- Most additives such as flame retardants, antioxidants and processing aids increase the relative permittivity.