Study shows that zwitterions can raise the dielectric constant of soft materials

17 December 2021, by Ingrid Fadelli

Six different zwitterions all strongly increase the dielectric constant of soft matter (here demonstrated in ethylene glycol solutions). The 3-carbon propyl spacer connecting anion and cation has a smaller dipole than the 4-carbon butyl spacer, making the latter somewhat more effective at raising dielectric constant. Credit: Mei et al.

To create efficient energy storage solutions and actuators, engineers need materials with a high dielectric constant. The dielectric constant is essentially the ratio of a substance's permittivity (i.e., its ability to store electrical energy in an electric field) to the permittivity of free space.

A valuable approach to increase the dielectric constant of materials entails incorporating polar additives with a high dielectric constant. While this strategy has achieved promising results, so far, the dielectric constant is not high enough for many applications.

Researchers at Penn State University have recently introduced an effective new method for raising the dielectric constant of soft materials. This method, introduced in a paper published in Physical Review Letters, involves the addition of zwitterions, small molecules with one positive electrical charge (i.e., cation) and one negative electrical charge (i.e., anion), separated by covalent bonds.

"Since 2006, the Colby group has studied polymeric single-ion conductors that conduct one and only one type of ion (such as Li for batteries)," Ralph H. Colby, one of the researchers who carried out the study, told Phys.org. "Currently, while the transference number is very close to unity (meaning they are single-ion conductors) the ionic conductivity is too low. So, for many years we have added low volatility polar molecules that boost conductivity."

Zwitterions are non-volatile molecules that are highly polar. Notably, they are the most polar molecules that Colby and his colleagues have experimented with. In their recent experiments, the team added the zwitterions to polymeric single-ion conductors.

"To be successful as additives to boost ionic conductivity of single-ion conductors, additives need to do two things: raise dielectric constant to soften all the ionic interactions that slow down ion transport and lower the glass transition temperature to make all molecular motions faster," Colby explained. "Zwitterions are great at the first one and we are now trying to design zwitterions that can also lower the glass transition temperature."

The paper demonstrates that adding zwitterions to soft materials can significantly increase the dielectric constant. This increase could be associated with the large molecular dipole of zwitterions, which ranges from 35 to 41 Debye.

When they added several zwitterions to ethylene glycol, the team observed a nonlinear increase in the dielectric constant. This increase eventually saturated at values above 200, due to the strong

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Coulombic interactions between the zwitterions.

These findings suggest that zwitterions are highly promising additives for boosting the dielectric constant of soft materials. In the future, they could thus have important implications for the development of energy storage tools, actuators and various other technologies.

“Our most notable finding is that adding zwitterions to any soft material can easily make the dielectric constant larger than 100,” Colby said. “The dielectric constant of water is about 80 at room temperature so dielectric constant of 100 should be sufficiently high. Our ongoing work adds the zwitterions studied here to polymeric single-ion conductors and tries to develop zwitterions with larger dipoles and lower glass transition temperature.”


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