I. D. Brindle
and **R. H. Tomlinson**
McMaster University
Hamilton, Ontario, Canada

Deflection of Falling Solvents by an Electric Field

The CHEM Study film[1] "Shapes and Polarities of Molecules" shows a simple method of distinguishing polar and non-polar solvent molecules. It demonstrates that if a stream of a polar solvent is allowed to flow from a buret past a charged rod, it is deflected towards the rod whereas the non-polar solvent is not affected.

The film does not indicate that, under appropriate conditions, it is possible to obtain spectacular deflections from such non-polar solvents as CCl_4. It has been found that when the humidity is low, significantly higher charges may be obtained by rubbing such common insulators as glass or ebonite and these cause the deflection of both polar and non-polar solvents. It is possible, for example, to cause a stream of CCl_4 to rise upwards from the tip of the buret and spiral around a charged rod several times before shattering in a spray as it strikes it. This effect is enhanced at low flow rates. When the solvent would be dripping in the absence of the field, it is drawn into a filament-like continuous stream in the presence of a large electric field.

In view of these observations, which are the normal behavior when the experiment is conducted in the dry conditions of the northern winter, it was appropriate that the whole basis for the polar molecule explanation for the phenomena shown in the CHEM Study film be questioned.

Charged rods of either polarity cause the free falling liquids to be attracted. In the CHEM Study film this is given as evidence that the force of attraction on the fluid is the result of the molecular dipole rather than a formal charge on the liquid. Such a conclusion would only be valid if the charge were developed by some flow mechanism and were independent of the charge on the rod. If, however, the charge on the liquid is induced by the charged rod, then the attraction would be expected to rods of either charge. The failure of the CHEM Study film to explore this possibility has made the remainder of the film discussing this phenomenon very misleading. Furthermore, it is possible to calculate the magnitude of an electric field which would be required in order to visually deflect a falling liquid. Even if thermal agitation did not affect the orientation of the dipole, it would require fields of the order of 10^5 V cm^{-1} to give a force comparable to gravity on the liquid, and hence cause significant deflections. Since such fields would cause discharge through the air, it would seem that a formal charge on the liquid would be more likely to account for the observations. For a field of 10^4 V cm^{-1} a charge resulting from the gain or loss of some 10^7 electrons mg^{-1} would be sufficient to account for the deflection. This system would be analogous to a Milliken oil drop experiment.

Several experiments were performed to determine the extent to which formal charge on the falling liquid is involved in its deflection.

1) The falling deflected liquid was collected in a metal cup connected to a gold leaf electroscope. This confirmed that the falling liquid is charged. The sign of the charge is found to be opposite to that on the rod causing the deflection. If the liquid is collected one drop at a time, there is a significant increase in charge associated with each falling drop.
2) The liquid in the buret was connected to an electroscope by means of a wire extending down through the liquid in the buret. This also demonstrates a charge acquisition as the fluid flowing from the buret is deflected. The sign of the charge on the liquid in the buret is the same as on the rod causing the deflection. The observations of these two experiments are consistent with the classical observations of electrostatic induction. This latter experiment can be performed in a different way which more clearly shows the importance of induction. If this fluid is allowed to fall into a metal cup connected to an electroscope as in experiment (1), no charge is found to accumulate without the influence of a charged rod. If, however, a charged rod is held close to the surface of the fluid at the top of the buret, the collected fluid shows a charge which is the same as the charged rod. Some further experiments demonstrate that formal charge on the falling liquid is the origin of the only force that is significantly influencing the visual aspect of the phenomena.
3) The charged rod causing the deflection of the falling liquid was clamped into position while a steady stream of liquid was falling from the buret. The extent of the deflection decreases with time, eventually falling to zero if the buret is properly insulated. If a wire dipping into the buret is grounded, however, the deflection is restored to its original extent. If the dipole interaction were significant the deflection would only decrease with a decrease in charge on the rod. It is concluded that as the charge on the liquid in the buret builds up, the potential gradient causing the deflection is eventually reduced to zero. Grounding the liquid in the buret restores the field gradient between the charged rod and the tip of the buret and, therefore, the deflection.
4) Using the same arrangement as in (3) above, a grounded metal rod is brought towards the falling deflected liquid. When this grounded rod is brought up parallel to the charged rod and on the same side of the falling liquid two types of observations are possible. If the grounded conductor is close and below the charged insulator, the deflection of the liquid is opposed and depending on the relative positions the net deflection of the falling liquid may be zero or even away from the two rods. Since the grounded insulator also acquires an induced charge, opposite to the charged rod, its charge is the same as that of the falling liquid. Since dipole orientation is very rapid this arrangement should cause enhanced deflection if molecule dipole orientation played a significant role. This is not what is observed. One of several interesting variations of this experiment is to bring the grounded metal rod close to the falling liquid but at some distance below the charged rod. Under these conditions the liquid deflection is enhanced. The charge on the liquid is sufficient to induce a charge on the grounded rod which is now the same as that of the charged insulator and this causes further deflection when the two rods are on the same side of the falling liquid.

Since it is clear that the primary cause of the deflection of the fluid is an induced charge, it is important to consider what property of the liquids determines the extent of this charge. In the CHEM Study film the solvents, whose molecules were polar, were correctly distinguished from the non-polar solvents although at higher field strengths we have shown that this distinction is not as obvious. An important observation is that the extent of the deflection,

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[1] Dows, D., CHEM Study film = 4154, Modern Learning Aids, 1212 Avenue of the Americas, New York, N.Y.

for those whose deflections are least, is enhanced at low flow rates. As the time required to orient the molecular dipoles is very fast in relation to visual observation, it would appear that the solvent conductivity is the limiting factor in determining the extent of deflection.

The conductivities of several common solvents were measured and the tendency to be deflected has been qualitatively correlated with these. The conductivities of solvents taken directly from the shelf are frequently many orders of magnitude greater than those reported for them in the literature. Indeed conductivity is one of the more sensitive indicators of purity. Two nominally similar *cis*-1,2-dichloroethenes showed a factor of 10 difference in conductivity from each other but had 100 and 1000 times greater conductivity than a shelf sample of the trans form. The success of the CHEM Study experiment in correctly sorting the polar and non-polar solvents is, therefore, not entirely coincidental. Those solvents with the greatest molecular polarity acquire, through impurities such as water, the greatest conductivity. If the conductivity of the solvent is sufficient that in the presence of an electric field of the order of 10^4 V/cm it can acquire a charge of some 10^7–10^8 electrons per mg, in the time that the liquid passes through the field, then significant deflections of the falling solvent will be observed.

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