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LV. A study of Franklin's Experiment on the Leyden Jar with movable coatings

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small rise to 2·41 at 80° A. The present arrangement did not permit of an accurate determination as to whether there was an actual discontinuity in the value of the dielectric constant at the melting-point, or whether the change took place in a small range of temperature. The former alternative is probable, and the change is so represented in the graph (fig. 2).

Summary.

A method is described for the determination of the dielectric constants of liquid or solid substances by the aid of triode valve circuits. The results obtained by this method for the dielectric constants of methyl, ethyl, n-propyl, and n-butyl formates, and the corresponding acetates at the temperature of liquid air, are then given and compared with the values obtained by other investigators at ordinary temperatures. It is shown that at the low temperatures the acid radicle apparently contributes but little to the value of the dielectric constant. Results showing the dependence on temperature of the dielectric constant of n-butyl acetate throughout the range of temperature 292° A–80° A are also given. It is found that the dielectric constant of this substance increases linearly with decrease of temperature down to the melting-point, at which a sudden fall in the value occurs, followed by a very gradual rise as the temperature is further lowered.

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LV. *A Study of Franklin's Experiment on the Leyden Jar with Movable Coatings.* *By* G. L. Addenbrooke, *M.I.E.E.**

To understand the actions in dielectrics it is very desirable to have a clear idea of the principles which underlie electrostatic actions. For the most part these can be found in text-books, but there is one respect in which they are all defective, and that in connexion with one very

* Communicated by the Author.

important action which bears largely on a class of problems which has much practical importance.

This is known as the "Franklin Experiment" on the Leyden Jar with movable coatings.

The experiment in its simplest form is briefly thus :—The jar is charged, the inner coating is lifted out by an insulated hook, and this inner coating is then touched against the outer coating and put back. It is found that when taken out the inner coating carries scarcely any charge, and that when it is put back a full or nearly full discharge can be got from the reconstituted jar.

The experiment is sometimes varied by placing the charged jar on an insulating stand and taking away by insulated tongs both the covers, leaving the glass jar exposed. Both covers are found to be practically uncharged, they are then touched against each other. The whole jar and coatings are next reconstituted, when a full discharge can be obtained.

This has been taken to mean that when a dielectric between two electrodes is charged, if the electrodes are taken away while still charged, the energy of the charge is left stored in the dielectric, and remains there until the electrodes are restored and short-circuited, or the charge dies down by some indefinite form of leakage.

For a long time I could not reconcile this experiment and its general interpretation with the views I had been led to form of electrical actions in dielectrics in other respects. I therefore searched through a number of works for the purpose of finding any variations there might be in the methods of performing the experiment, or in the explanation of it, when I noticed that there seemed to be no mention of it in Faraday's or Maxwell's work. It is not mentioned in Gordon's 'Electricity and Magnetism,' nor in Sir J. J. Thomson's Text-book, though it is described in Poynting and Thomson's 'Electricity and Magnetism' of 1914. This was significant, though it seemed almost equally significant that if the experiment was omitted for any reason, no reasons should be given for so doing.

At last, to clear up the matter there seemed no other course but to investigate it further oneself.

In considering how to do this the first point which struck me was that a glass jar was invariably mentioned as the dielectric.

The question arose what would happen if another dielectric were substituted.

Finally, solid paraffin was selected as a suitable substitute on account of its high insulating properties, and because its surface is not so hygroscopic as glass. After some trouble I succeeded in casting a thin but perfect jar of paraffin fitting the same metal coatings as a glass jar I had.

The usual experiment was tried with this, but instead of charging the jar from an electrical machine, the jar was connected to a gold-leaf electroscope and charged from an electrophorus.

By this method one does not need such high potentials, there is less loss from leakage, and it is possible to see what is going on and make approximate quantitative measurements.

In this way the jar was charged to 500–600 volts, and the deflexion on the electroscope noted. The inner coating of the jar was then lifted out by an insulating handle, touched to the outer coating and replaced. It was then re-connected to the electroscope. Contrary to the case with the glass jar there was no appreciable charge remaining in the jar; in fact, repeated experiment showed that on lifting out the inner coating and earthing it, or connecting it to the outer coating, the dielectric was completely discharged in the act, and only the barest trace of charge remained when the inner coating was put back. Also the charge evidently came away on the inner metallic coating when it was lifted out, as could be plainly seen on the electroscope. In fact, the action was exactly the reverse to the account of it usually given. On the other hand, the actions as now found seemed completely in accord with the Faraday-Maxwell theory, and with known electrostatic laws. Briefly they showed, that the action on the dielectric is inductive, that if the inner charged electrode were brought outside, the lines of force going to the outer electrode no longer went through the dielectric, which accordingly lapsed to its normal and neutral state.

If when the jar with paraffin dielectric is charged it is placed on an insulated stand and both coatings are taken off by insulated handles, both coatings will be found to have strong and equal charges of opposite signs. If these two coatings are then touched together, and the jar is reconstituted, it will be found to have no charge as before.

Having thus clearly shown that there is a difference in the results of the experiment when glass is used and a better dielectric such as paraffin, I determined to vary the glass experiment as follows:—The glass jar was first thoroughly warmed. It was then put in a large dry cupboard, and kept dry for a couple of days by means of plenty of calcium chloride.

This dry cupboard is so arranged that, by means of oil silk sleeves passing through holes in one of the sides, and wearing rubber gloves, one can manipulate inside without introducing moisture.

The Franklin experiment with glass dielectric was then repeated with the dried glass in a thoroughly dried atmosphere.

The effects observed were now no longer the same as before, but were the same as described with the paraffin jar. That is, after charging and taking out the inner coating and touching it to the outer coating and replacing, there was only a slight charge remaining, due doubtless to absorption. For all practical purposes the characteristic actions as described in the text-books were wanting, and the results come in line with the Faraday-Maxwell theory.

It is clear from other experiments I have made (see Physical Society's Proceedings, 1912) that, in the case of the glass jar, condensed moisture on its surface is under all ordinary circumstances sufficient to form a semi-conducting film, of high resistance, but sufficiently conducting for the charge on the electrodes to escape to it when one is removed, or before, especially as when the experiment is tried under conditions as above, the electroscope shows that if the electrodes are separated the same action takes place as when the cover is removed from an electrophorus, that is as the electrodes are separated their difference of potential rapidly increases.

This is more the case as the dielectric constant of glass is so high that the slope of the potential is chiefly concentrated on and is very great across any small air space between the glass and the electrodes.

A small motion of the electrodes already charged to a fairly high potential, therefore, raises this potential at least two or three times so that there is a strong tendency for the charge to flow to the glass surface, even if there is only momentary contact at two or three points.

I have related my work on this experiment at some length because it became more and more clear to me that to arrive at any clear understanding of the actions of electric fields on dielectrics, the correct interpretation of the experiments is essential.

It has always appeared to me that this experiment was about the most striking and most fundamental in all the realm of electrostatics. It seemed so convincing that for many years I, and I know numbers of others, have accepted it and still do without question, as ordinarily interpreted.

It is such a striking experiment that when I began to doubt its interpretation it appeared to me that to leave it without rational explanation left a fundamental point in an undecided state, as there was no other experiment which gave an equally convincing demonstration of the real actions.

In drawing attention to this matter I trust it may not lead to teachers abandoning the experiment, as it is now omitted in some cases. As reconstructed, besides demonstrating the main theoretical point, it brings into prominence the other actions, and coordinates these actions with the behaviour of the electrophorus and other electrostatic facts, while it also draws attention to the question of leakage and surface effects which are very indefinitely understood at present but which are being found increasingly important.

Instead of being tried only with a glass jar I would suggest that the experiment be tried also with a high-class ebonite jar, which would be less fragile than paraffin, as I think it would succeed if the ebonite was kept in the dark in a closed glass jar with calcium chloride up to the moment of use. It is difficult to speak definitely of glass, its surface state varies so, but I think in most cases if the experiment were tried as usual, and then the glass jar were heated to 100° C. and kept over calcium chloride for 20 minutes till it was cold, if the experiment was then quickly made in the open air, it would be found to fail from the Franklin point of view, although it succeeded well in the first trial.

LVI. *A New Model of Ferromagnetic Induction.* *By* Sir J. Alfred Ewing, *K.C.B., F.R.S., Principal of the University of Edinburgh* *.

I HAVE lately reconsidered, in the light of what is now known about atomic structure, the theory of induced magnetism in iron and other ferromagnetic substances which I put forward more than thirty years ago, and have come to see that it needs substantial amendment. A new model of the process of ferromagnetic induction has to take the place of the model then suggested. The new model is the subject of a recent communication to the Royal Society (Proc. Roy. Soc. Feb. 1, 1922), but a brief account may be offered to the Philosophical Magazine, in which the model of 1890 was described on its first introduction †.

The revised theory and the new model retain this fundamental feature, that there is in every ferromagnetic atom a Weber element possessing magnetic moment and capable of

* Communicated by the Author.

† Phil. Mag., 5th series, vol. xxx. p. 205 (Sept. 1890).