But $k = \ln (2\,c/b) - 1$, and if $\ln (c/b)$ is much greater than 1, we can write

$$F_z = \frac{E^2 c^2}{8} \, \frac{2 \ln b/c}{(\ln b/2\,c)^2} \, . \tag{15a}$$

Note added in proof. Dr. DE QUERVAIN has drawn our attention to a short paragraph in a paper by E. MELCHER (ZAMP *2*, 1951) who found that the structure of *rime* was influenced by a radial unipolar electric field (the polarity being immaterial) but that an alternating field had no effect.

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Zusammenfassung

Das Wachstum von Eiskristallen in einer Diffusionswolkenkammer wird durch ein elektrisches Feld von über 500 V/cm wesentlich geändert. Die Kristalle wachsen sehr schnell in Form langer, dünner Nadeln. Die Ursache des beschleunigten Wachstums ist noch nicht völlig erkannt; aber die Beobachtungen stimmen mit der Hypothese überein, dass die Kristalle durch Einbau von neutralen Wassermolekülen wachsen.

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Use of the Electrostatic Analogy in Studies of Ice Crystal Growth[1]

By JAMES E. MCDONALD, Tucson, Arizona, U.S.A.[2]

1. Introduction

The distribution of water vapor density ϱ in the region surrounding an ice crystal growing under quasi-steady-state conditions satisfies LAPLACE'S equation

$$\Delta^2 \varrho = 0 \, . \tag{1}$$

Under typical conditions, neighboring crystals are sufficiently far apart that one may regard each one as growing at the expense of an infinite field of vapor. It follows that an analogy exists between the field of ϱ around such a crystal and the field of the electrostatic potential V existing around a charged conductor, of the same shape

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and size as the crystal, located infinitely far from any other bodies. The analogy depends upon the facts that (1) V also satisfies LAPLACE's equation, and that (2) the hypothesized geometrical similarity implies analogous boundary conditions in the two cases, so long as the surface distributions of ϱ and V are identical.

This latter requirement, often glossed over in treatments of the analogy, is satisfied as a result of almost adventitious circumstances. Clearly, in the electrostatic case, the potential must have some uniform value V_0 over the entire surface of the crystal-shaped conductor, by the very definition of a conductor. Physically, this uniformity is achieved by actual movement of charge within and over the surface of the conductor. To preserve the full analogy, the surface value ϱ_0 of the vapor density must also be uniform over the growing (or evaporating) ice crystal, which evidently demands uniformity of the surface temperature T_0, since ϱ_0 must equal the saturation vapor density corresponding to the local temperature of any small portion of the crystal. But the latter temperature is controlled jointly by (1) the local rate of release of latent heat of sublimation which in turn is controlled by the local vapor-flux density, and (2) the local rate of conductive efflux of heat from the relatively warm, growing crystal. That this complex set of factors governing the distribution of values of ϱ_0 over the growing crystal does, in fact, yield constant ϱ_0 over the full surface hinges upon the further analogy between vapor diffusion and heat conduction, whereby the very portions of the crystal which are being fed vapor at the fastest rates are also losing heat at *exactly* corresponding rates. We thus see that the constancy of ϱ_0 over the entire crystal surface does yield exactly analogous boundary conditions to those for the electrostatic case, but for physical reasons quite unlike those involving charge movement over a conductor.

Having established the full mathematical analogy between the diffusion problem and the electrostatic problem, it quickly follows, by arguments based upon GAUSS' law and FICK'S law of diffusion, that the rate of increase of crystal mass m can be written in the useful form

$$dm/dt = 4\,\pi\,C\,D\,(\varrho_1 - \varrho_0) \tag{2}$$

where D is the vapor diffusivity, ϱ_1 is the vapor density at infinity, and C is the electrostatic capacitance of the hypothesized conductor of shape and size identical with that of the ice crystal. Discussions of the steps leading to (2) have been given by MASON [1][3]) and more briefly FLETCHER [2].

The writer's study of the history of the exploitation of this type of analogy shows it to be rather different from what is usually indicated in the meteorological literature. A very brief summary may be relevant here. HOUGHTON [3] appears to have been the first to use (2) in a discussion of ice crystal growth in the atmosphere. His citation of JEFFREYS [4] has been misconstrued by others to mean that the idea of obtaining the solution to a difficult vapor-diffusion problem by appeal to electrostatic analogy actually originated with JEFFREYS. Casual reading of the latter's paper might even leave one with that impression; but study of an 1881 paper of J. STEFAN, which JEFFREYS cites, makes quite clear that JEFFREYS drew his idea from STEFAN, who, in turn, in an 1873 paper on evaporation from tubes and circular liquid surfaces, makes very clear that the idea was not original with him. He attributes the analogy

[3]) Numbers in brackets refer to References, page 619.

to MAXWELL, who used it in 1875 to discuss a meteorological instrumentation problem, that of the vapor exchange at the surface of a wetbulb psychrometer. By the time MAXWELL was writing, the corresponding analogy between heat conduction and the electrostatic field was well known, WILLIAM THOMSON (later LORD KELVIN) having written what may be the earliest paper thereon in 1841 at age 17. In brief, it appears correct to attribute to MAXWELL the first systematic treatment of the particular analogy between diffusion and electrostatic fields, and to attribute to HOUGHTON the first direct use of it in ice-crystal growth studies.

2. Theoretical Determinations of *C*

The analogy is useful to the investigator of diffusional growth only to such extent as he can find, in the literature of electrostatics, previously established values of C for shapes corresponding to the crystals whose growth he wishes to predict from Equation (2). As far as *theoretically* determined C-values are concerned, it may be viewed as almost an historical accident that we find the desired solutions to LAPLACE'S equation in the literature of electrostatics, rather than in the literature of diffusion. Were it opposite we would find students of electrostatics using the 'diffusion analogy' to cull C-values from the diffusion literature. On the other hand, *experimentally* determined C-values are much more easily obtained from electrostatic measurements than from diffusional measurements, a circumstance to be exploited below.

For reference and for later use, we may note that since LAPLACE'S equation is soluble for certain highly symmetric shapes corresponding to certain orthogonal coordinate systems (in which LAPLACE'S equation proves to be separable), we can get theoretical C-values for those shapes from works on electrostatics. The following four are those most likely to be of interest in ice crystal studies:

(a) Sphere or radius r. $C = r$.
(b) Thin circular disk of radius r. $C = 2\, r/\pi$.
(c) Prolate spheroid of major and minor semi-axes a and b, respectively.
$C = A/\ln[(a + A)/b]$, where $A = (a^2 - b^2)^{1/2}$.
(d) Oblate spheroid of major and minor semi-axes, a and c, respectively.
$C = a\, e/\sin^{-1} e$, where e is the profile eccentricity, $e = (1 - c^2/a^2)^{1/2}$.

It can be shown from (c) that the limit of C for a very long, thin, prolate spheroid, approximating ice-needle form, is $C = a/\ln(2\, a/b)$, and from (d) that the limit of C for an oblate spheroid of extremely small minor axis is $C = 2\, a/\pi$, i.e. the same as given in (b) for the circular disk. Of course, (c) and (d) go over into (a) in the limit of zero profile eccentricity.

HOUGHTON [3] used (a), (b) and (c) in giving the first adequate quantitative assessment of the Bergeron-Findeisen theory of crystal growth. His approach, involving approximation to a thin tabular plate or dendrite through use of (b) and to ice needles through use of (c) would seem to promise reasonable estimates. However, the only way to check the latter assertion, and the only simple way to obtain C-values for still other shapes of interest in ice-growth studies, is to resort to experimental determinations of C. The next two sections will discuss a series of such determinations.

3. Experimental Determinations of *C*

Procedure. In the electrostatic analogy, *C* is the capacitance of a crystal-model conductor in an *infinite* region, whereas in any laboratory measurement, only a finite distance from object to adjacent boundaries can be achieved. To optimize the approximation, one must use small model conductors in the largest available test space, and then one must find some method for determining the model-to-boundary capacitance. Since such a technique will surely contain systematic errors associated with the departure from ideal conditions, some calibration technique must be utilized.

It was originally hoped that *C* could be experimentally measured for most observed crystal forms, and so a number of habits were modelled in brass. Figure 1

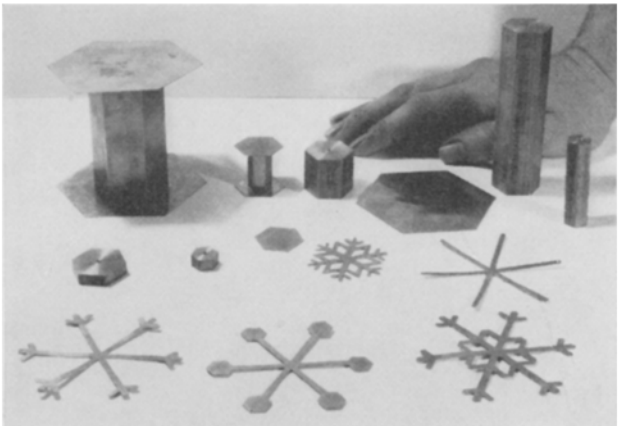

Figure 1
Brass test-models of various ice crystal forms used in capacitance determinations.

shows a few of these. In the end it was concluded that the methods employed precluded accurate evaluation of such rare forms as the tsuzumi, and even the hexagonal prism types could only be estimated rather roughly, as will be explained below.

Several experimental approaches were tried before acceptable results were obtained. The following scale considerations imply difficulties: The capacitance of an isolated sphere of radius *r* cm has a capacitance, according to (a) above, of only 1·111 μμf (micromicrofarad), a fairly small capacitance by ordinary measurement standards. On the other hand, if the tests model is suspended within a Faraday cage, the infinity approximation demands that the model be fairly small relative to the cage dimensions. First trials, using models of characteristic dimensions near one centimeter in a cubical cage 1 m on edge, with the capacitance measured with the aid of a square-wave multivibrator discharging through the unknown capacitance in a counting-rate meter circuit gave only marginally acceptable precision. Consequently both a larger Faraday cage and a more sensitive capacitance-measuring scheme were sought.

All of the final measurements discussed below were carried out with test models suspended at the center of a walk-in size Faraday cage (E. A. LINDGREN *et. al.* minimum rf-interference chamber), 7·5 ft high on a base 6·5 by 10 ft. A General Radio Type 1610-A Capacitance Measuring Assembly, operated at 100 kc/s and 10 volts afforded quite adequate precision with the larger test models permitted by the larger cage dimensions. For example, a standard deviation of 0·04 μμf was obtained in a series of 10 repetitions of C-determinations for a single specimen. Sensitivity to location within the cage was found to be quite small; a single test specimen could be moved several feet off the regularly-used central suspension point without any detectable change of measured capacitance. Thus both cage-size and measuring gear were, with this apparatus, not the limiting factors.

Instead, the limiting factor stemmed from the additive effect of the *parallel* capacitance unavoidably introduced by insertion of the lead-wire required to make the C-measurements. Whereas the desired goal was to measure C for a truly isolated specimen in a large test-region free from other objects, one must, of course, attach one lead wire to the specimen in order to measure the capacitance between specimen and surrounding cage. If only this additive parallel capacitance of the lead wire (which, in practice, also constituted the suspension member to hold the specimen directly below its small access hole in the top-center of the cage) were the sole effect, calibration techniques on objects of known C would give extremely high accuracy, indeed, far higher accuracy than would be of any use in cloud physics work. But, in fact, a further interference effect whereby the lead-wire shorted out a portion of the lines of flux that should otherwise have run from cage-walls to specimen led to a variable effect depending upon specimen size. Using several classes of objects whose capacitances were theoretically predictable, it was found that the apparent C always sank relatively lower, compared with the theoretical value, as object-size diminished. Table 1 displays this effect for the particular case of test objects in the form of thin circular discs made of sheet brass of thickness 0·33 mm. The entries identified in Table 1 as 'theoretical C-values' were calculated from relation (b) above, i.e. for the case of a completely isolated disc of each given size. It can be seen that as one goes to smaller and smaller test specimens, the field short-out makes an increasingly larger relative reduction in the measured value of the additive capacitance introduced by affixing the specimen to the end of the lead wire. Since there is no easy way in which this short-out reduction can be accurately predicted from first principles, it seriously limits the appl'cability of this whole technique. It does not, however, preclude learning a few interesting and moderately useful relationships about C-values of crystal shapes, as will now be shown.

Table 1

Effect of lead-wire field short-out on measured capacitance of test discs of various sizes (all discs cut from 0·33 mm sheet brass)

Disc radius (cm)	5·08	4·45	3·82	3·18	2·54	1·91	1·27
Measured C (μμf)	2·56	2·18	1·79	1·43	1·08	0·75	0·43
Theoretical C (μμf)	3·60	3·15	2·70	2·25	1·80	1·36	0·90
Ratio (measured/theoretical)	0·71	0·69	0·66	0·64	0·60	0·55	0·48

Results. The following information on hexagonal plates, dendritic forms, and needle forms is regarded as reliable to within error-limits quite adequate for cloud physics applications. The data on hexagonal cylinders are reported, but are not readily interpretable in completely unambiguous fashion. No C measurements will be reported on other more elaborate forms since field short-out completely blocked useful interpretation of such results.

1. *Capacitance of thin hexagonal plates.* It seems reasonable to anticipate that C for a thin hexagonal plate ought to lie intermediate between the capacitances of thin discs of outline corresponding to the inscribed and the circumscribed circles. A more specific guess might be that C would equal that of a circular disc of equal area. If we call the edge-length of one side of the hexagon S, then the radius r of the circle of equal area satisfies the relation $r = 0{\cdot}91\ S$. Hexagonal plates were cut from the same brass stock used for the discs tabulated in Table 1, with hexagon dimensions calculated to yield the same face-area as that for each of five discs of that series.

Comparative results are shown in Table 2. They indicate that one will be quite close to the correct value to assume that *thin* hexagonal plates have the same C as ideal thin discs of equal area, the experimental error being only a few per cent for all but the smallest specimen pairs considered. Since the short-out effect becomes most important for the small sizes, the error for the 1·27 cm discs and equivalent plate is probably rather larger than the others, exaggerating the reduction in measured C for the hexagon of that pair.

Table 2

Comparison of C for thin hexagonal plates and thin circular discs of equal area

Disc radius (cm)	3·82	3·18	2·54	1·91	1·27
Measured C ($\mu\mu$f)	1·79	1·43	1·08	0·75	0·43
Hexagon edge S (cm)	4.18	3.49	2.79	2.09	1.40
Measured C ($\mu\mu$f)	1·81	1·42	1·10	0·72	0·47
Per cent excess disc over hexagon	−1·1	0·7	−1·8	4·2	−8·5

2. *Effect of thickness on C for hexagonal plates.* The theoretical value of C for circular discs assumes vanishingly small thickness. It is of interest to ask how sensitive C is to the finite thickness of actual hexagonal tabular ice crystal shapes. Field short-out precludes exploring this effect over an extremely large range of thickness; but already-cited results justify confidence in conclusions drawn from specimens of only moderate thickness. Hexagonal plates, all of edge length $S = 3{\cdot}81$ cm, were cut from brass stock varying in thickness from 0·33 mm to 4·82 mm and their capacitances measured by the same techniques previously used. Results are set out in Table 3.

Table 3

Thickness effect on C for hexagonal plates, $S = 3{\cdot}81$ cm for each

Thickness (mm)	0·33	0·84	1·27	2·28	4·82
Measured C ($\mu\mu$f)	1·71	1·70	1·75	1·81	1·93
Relative value	1·00	0·99	1·01	1·04	1·12

In the last line of Table 3, each measured C has been expressed as a multiple of the value found for the plate of 0·33 mm thickness. It is seen that the increasing thickness does not yield an increase of C in excess of one per cent until the thickness is increased somewhat beyond 1·27 mm. The last two values suggest the rough rule that when the thickness of hexagonal plates equals 10 per cent of the edge-length the capacitance rises to about 10 per cent above that of an ideal circular disc of the same face-area. It is also of passing interest to note that the sum of the six prism-face areas of the specimen of 4·82 mm thickness is equivalent to about 0·14 times the sum of the two basal-face areas of that specimen. This suggests an alternative rough rule that the enhancement of C due to finite thickness is approximately proportional to the increase in *total* surface area over that of an infinitesimally thin hexagonal plate of same basal area. Unfortunately, one cannot test either of these rules over much greater thickness range, for the uncertainty in field short-out effect grows too great if the thickness departs much further from the first (Reference) value used in Table 3.

3. *Needle forms.* As was noted earlier, the limiting value of the capacitance of a long, thin prolate spheroid is

$$C = \frac{a}{\ln(2\,a/b)}\,, \tag{3}$$

where a is half the 'needle' length, and b is the radius of the midsection. Some exploratory measurements were made on long thin *cylindrical* specimens to examine how b-variations might influence measured C-values. If no significant C-increases were found to accompany moderate increases in b form some very small reference value, then it was felt that the conclusion could be drawn that *all* of the specimens lay in the range of small b for which (3) holds fairly accurately.

Table 4 displays results for five thin cylinders of increasing radius b, all with length $2\,a = 15{\cdot}2$ cm. The fact that the ratio of measured capacitance (including the unknown field short-out effect) to the theoretical value computed on the basis of the asymptotic form (3) for the capacitance of a prolate spheroid increased only from 0·73 to 0·78, as b was increased more than twentyfold, is interpreted to mean that in this range of fairly small b/a values (maximum about 0·05) one may use (3) even for cylinders and hence probably also for ice needles of hexagonal cross-section of correspondingly small fineness ratios.

Table 4

Effects of variations of thickness on cylindrical specimens of radius b (all lengths were 15·2 cm)

b (cm)	0·0318	0·0418	0·0635	0·155	0·765
Measured C (μμf)	0·89	0·96	1·08	1·26	1·81
Theoretical C (μμf)	1·23	1·29	1·38	1·61	2·31
Ratio (measured/theoretical)	0·73	0·74	0·78	0·78	0·78

4. *Hexagonal prisms.* Capacitances of a series of hexagonal prisms of varying length whose cross-section measured 2·54 cm from flat to flat (i.e. normal to opposite prism faces) were measured. That the results shed at least some light on C-values of such forms is roughly indicated by the following: The particular specimen of length 15·2 cm (same as 'needle' specimens of Table 4) yielded a measured C of 2·95 μμf. If we use (3) to predict a theoretical C-value for this shape, taking for b half the flat-to-flat distance, we find that the ratio of measured to theoretical C is

0·86. This is not very far above the ratio of 0·78 that was found for the largest specimens of Table 4; hence it appears that even in this large b/a range, C for hexagonal columns may be predicted with tolerable accuracy by the limiting relation (3); and still finer hexagonal columns can be even more accurately treated by the same equation.

For this reason, experimental C-values are given, for possible reference use by other investigators, in Table 5, without further comment, except to warn that the shortest lengths involve rather uncertain short-out effects and hence are probably of very limited value in as much as one has no sure basis for correcting them.

Table 5

Measured capacitances of hexagonal prisms (see text for comments and explanation; all are of 2·54 cm 'flat-to-flat' diameter)

Length (cm)	25·4	20·3	15·2	10·2	5·08
Measured C (μμf)	4·32	3·57	2·95	2·17	1·40

5. *Dendritic forms.* Probably the most reliable and most interesting of the experimental C-measurements were those made on dendritic models. HOUGHTON [3] has suggested that the capacitance of such forms should be determined chiefly by their overall outline, i.e. that their fine structure should have little effect. The following results tend to confirm HOUGHTON'S view in that they show surprisingly small reduction in C accompanying fairly deep insection.

Comparative C-determinations were carried out with a total of fourteen models. All were cut from sheet brass of 0·33 mm thickness to keep that factor constant; and all were on the same fixed overall hexagon scale corresponding to $S = 3{\cdot}81$ cm, in order to hold the effects of field short-out essentially constant. Actually, it is very likely that, as the degree of insection becomes very great (e.g. models 11 and 12, Figure 2), the decrease in absolute C is accompanied by an increase in the relative

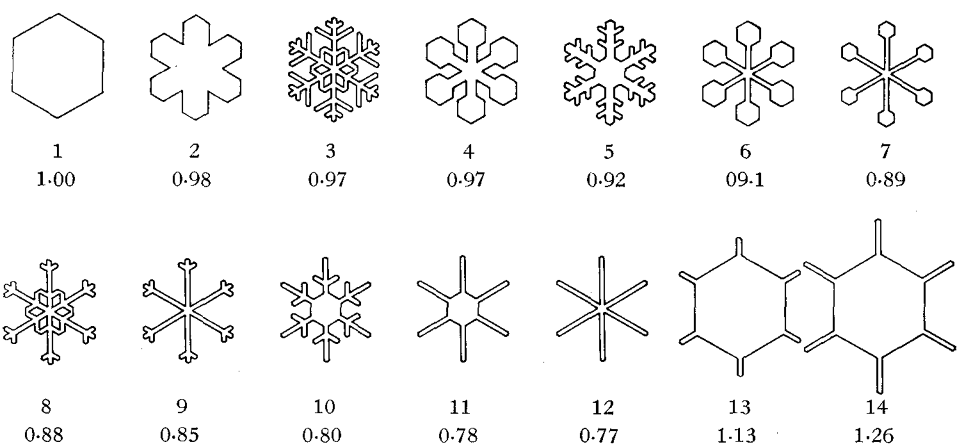

Figure 2

Forms and relative capacitances of fourteen dendritic models of ice crystals.

magnitude of the short-out reduction of *apparent C* (cf. Table 1), whence the C-ratios found here probably tend to overestimate slightly the true degree of C-reduction accompanying deep insection. That is, the true C for deeply insected forms is probably somewhat higher than here indicated. From experience gained from the study of the models summarized in Table 1, one might guess that the latter uncertainty is only of the order of a few per cent, however.

The dendritic models which were tested are displayed in Figure 2. Specimens Nos. 1, 6, 8, 9, and 12 may also be seen in the photograph of Figure 1. Since only relative values are of real interest, all C-values are expressed in terms of their ratio to that of model No. 1, the full hexagon, whose absolute capacitance may be predicted, as noted above, by use of the equal-area rule and the theoretical formula for C for thin circular discs. The ratios are entered in Figure 2 under each model number. The first twelve exhibit the surprisingly small C-suppression that accompanies quite deep insection. The fact that forms such as Nos. 3 and 4 have capacitances only a few per cent less than that of the corresponding full hexagon, and that so sparse a form as No. 12 should be only about 23 per cent less than the full hexagon, substantiates HOUGHTON'S qualitative conjecture.

A reasonable basis for understanding why the effect of insection is so small has been suggested to the writer by Dr. A. R. KASSANDER, JR. (personal communication): Although the total surface area is markedly reduced by insection, the total edge length rises, and the characteristic tendency for high charge density to appear on regions of locally high surface curvature, gives the increased edges and corners opportunity to hold the charge previously held on the flat surfaces that are eliminated as degree of insection increases. Viewed in terms of diffussion effects rather than in terms of charge-carrying capacity, one would say that the high vapor-flux density near the many edges and corners of the highly insected dendrite yields about as high a total arriving flux as that reaching the corresponding full hexagon. The area of model No. 12, in the projection shown, is only 0·19 times the area of model No. 1, yet its capacitance ratio is almost exactly four times higher than this ratio of 0·19, as a result of the large capacitance contribution of its many long edges. Actually, the problem is a bit more complex than just indicated, for if total edge-length alone were operative, a form such as No. 3 might be expected to exceed No. 1 in capacitance. Interior edges and corners that are nearly surrounded by other portions of the specimen are shielded (both electrostatically and diffusionally) by their neighbors in such a way as to make them less effective than the highly exposed edges of a form such as No. 12. Nevertheless, in a very general way, the counteracting effects of decreasing area and increasing edge-length and corner-frequency help to account for these results.

In the results for the last two models, Nos. 13 and 14, one might at first sense a contradiction to the above rule; but further consideration shows these results to be quite consistent with the previous results. The C-ratios show a marked rise in C as we let even rather narrow dendritic arms grow out from the six corners of our reference hexagon (in contrast to the only very small reductions of rather sizeable insections). For instance, the projected area for No. 14 is only 13 per cent greater than that of No. 1, yet its capacitance is 26 per cent larger. Here we have edge-corner-effects entering in an additive or reinforcing manner rather than in a counteractive manner as in the previous cases. Thus, adding thin arms not only increases area a bit but also considerably increases total edge and corner capacitance, whence C rises markedly. Looked at in another way, extension of the six arms make the overall form begin to act rather like a full hexagon of size circumscribed about the six arm extremities.

4. Discussion and Summary

The above experimental C-determinations offer a basis for estimating the accuracy of one's predictions of C from the four cited theoretical C-relations. The experimental method was found to be less conclusive than had initially been hoped, in as much as field short-out reduction of measured C (in the present parallel-capacitance approach), due to necessity of attaching a lead wire to the test model, introduces effects that cannot be quantitatively predicted from theory. However, from test runs with discs of known C, it was possible to learn enough about the short-out effect to place limits on its consequences. And by doing comparative runs with models all of nearly the same absolute size, the short-out error was minimized.

The present determinations of C for a number of ice-crystal forms have yielded some interesting results. Although these results certainly warranted the small amount of time and effort required to obtain them in the laboratory, it is to be noted that they fill only a rather minor gap in our knowledge of ice-crystal growth. That this is so was not conclusively demonstrable before the measurements were made, but is fairly clear from the above-reported results themselves. Briefly, the magnitude of the difference of actual C's for real crystal forms compared with theoretical C's for well-chosen analogs from the set of the four shapes for which C is analytically predictable is small enough that *other* uncertainties in prediction of actual crystal-growth are clearly of more concern to the theorist. A very relevant example is the *ventilation factor*. For the very conditions (i.e. absolute size of order of a millimeter) likely to lead to the more elaborate crystal forms, such as the highly-branched dendritic types, or, say, tsuzumis (Figure 1), the crystal's fall velocity is already so high that uncertainties in assignment of the proper ventilation factor loom larger than uncertainties in assignment of C.

Nevertheless, the experimental values do serve some useful purpose in showing that the latter is, in fact, the true situation. Furthermore, in *laboratory* studies of ice-crystal growth, where ventilation effects may be very low or even absent, C-variations may play a fairly large rôle in controlling dm/dt, and it is perhaps in the laboratory context that the present results may find their most useful application.

5. Remarks

I wish to acknowledge the assistance of FRANKLIN DAVIDSON, who made all of the test models. I also thank Dr. W. H. EVANS and Dr. A. R. KASSANDER, JR., for helpful advice and assistance. The support of the Office of Naval Research is gratefully acknowledged.

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Zusammenfassung

Der Bericht umfasst die Analogie zwischen Elektrostatik und Diffusion und die experimentelle Bestimmung der Kapazität von verschiedenen Formen von Eiskristallen.

(Received: May 3, 1963.)

Effet Faraday ionosphérique (I)

Par EMILE ARGENCE[1]), Saint-Louis, Ht. Rhin, France

1. Etude générale de la rotation Faraday

1.1 *Introduction*

1.11 Expériences de KERR et SHAIN

D'après les expériences relatives aux échos lunaires KERR et SHAIN [1][2]) ont réussi à mettre en évidence deux types de fluctuations: a) des scintillations rapides de période voisine de la seconde, b) des évanouissements lents de période voisine de la minute.

Les fluctuations rapides sont indépendantes de la hauteur de la lune au-dessus de l'horizon et dépendent de la manière dont la réflexion s'effectue. On les attribue en général à la présence d'hétérogénéités de différents genres distribuées au hasard sur la surface lunaire (sphère rugueuse). Théoriquement ce type de fluctuations permet de déterminer l'ordre de grandeur de ces hétérogénéités.

Les évanouissements lents ont leur origine dans l'ionosphère. Dans leur travail fondamental KERR et SHAIN [1] attribuaient au déplacement des hétérogénéités ionosphériques (nuages ionisés) l'origine des *fading* lents et trouvaient des vitesses de déplacement de l'ordre de 300 m/s dans la région $F2$, 50 m/s dans la région E. Cette interprétation se heurte à un certain nombre d'objections ainsi que l'a montré FOKKER [2].

1.12 Effet Faraday

D'après MURRAY et HARGREAVES [3] la cause du phénomène doit être attribuée à une rotation aléatoire du plan de polarisation des ondes traversant l'ionosphère et soumises à l'action du champ magnétique terrestre (effet Faraday).

BROWNE *et al.* [4] ont ensuite montré que la mesure de l'effet Faraday relatif aux échos lunaires permettait d'évaluer le nombre d'électrons contenus dans une colonne ionisée de section unité et de hauteur égale à celle de l'ionosphère. Des mesures systématiques furent alors entreprises par EVANS [5]. Pour lever l'ambiguité relative au nombre de rotations EVANS utilise deux fréquences distinctes et la variation du nombre d'électrons peut être déterminée en effectuant de nombreuses mesures durant des nuits successives.

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[1]) Institut franco-allemand de Recherches de Saint-Louis.

[2]) Les chiffres entre crochets renvoient à la Bibliographie, page 629.