



LXVII. On molecular aggregations produced in gases by sudden cooling

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LXVII. *On Molecular Aggregations produced in Gases by Sudden Cooling.* By GWILYM OWEN, M.A., M.Sc., Assistant Lecturer and Demonstrator in Physics, and A. LL. HUGHES, B.Sc., Oliver Lodge Fellow, University of Liverpool*.

IN the Phil. Mag. for Oct. 1907 we described some experiments which showed that certain gases after passing through a process of severe cooling contained large numbers of nuclei, the presence of which was shown by their ability to act as centres for the condensation of supersaturated water vapour. The following paper is an account of the continuation of those experiments.

I. THE CONDITIONS GOVERNING THE PRODUCTION OF THE NUCLEI.

In the paper referred to, it was shown that the gas had to be cooled below a certain temperature (which we called the "*critical temperature*") before the nuclei were produced. Since the term "*critical temperature*" has another meaning in Physics, it may be advisable to avoid using this term in future; we shall therefore throughout this paper employ the term "*nucleating temperature*" instead.

As stated in the previous paper, the number of nuclei produced depends upon the pressure of the gas and the temperature to which it is cooled. We have since found that the effect depends also upon the *rate at which the gas is cooled*. In fact the predominating factor in the formation of the nuclei appears to be *suddenness* of cooling.

It may be well here to describe the modification of the original apparatus which enabled the cooling of the gas to take place very rapidly. Figure 1 represents the original type of apparatus used. In performing an experiment, the bend C (which we call the "*tester*") was surrounded by a cold liquid and as the temperature of the gas fell, the pressure was kept constant at any desired value by running the mercury up in the reservoir B. Fig. 2 represents the new form of apparatus designed to allow the gas to be very suddenly cooled. As is seen from the diagram the tester X is made in the form of a spiral. A glass tap M is introduced between the tester and the reservoir B, while the tap D is replaced by a three-way tap D'. This new form of apparatus was used as follows:—With M closed, the tester is first

* Communicated by the Authors.

exhausted through D' to a low pressure by means of a water-pump and is then surrounded by the cold liquid. When the

Fig. 1.

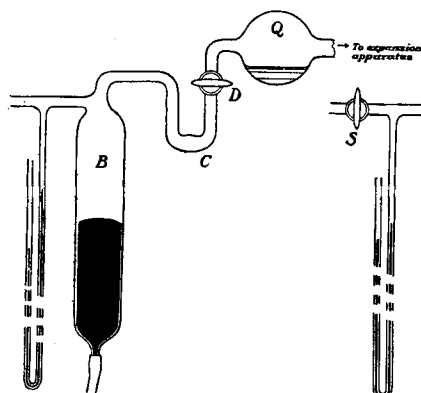
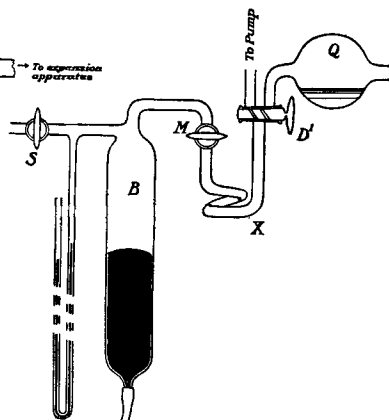


Fig. 2.



tester has attained the temperature of the liquid, the tap M is quickly turned and the gas rushes from B into it while the mercury is run up to bring the pressure to the desired value. After some thirty seconds, during which the temperature has risen about one degree, the cooling liquid is removed. The gas is then given a minute and a half to regain its normal temperature; at the end of which it is driven into the cloud-chamber Q where it is tested for the presence of nuclei. This method of cooling we shall denote as the "*sudden*" method, while the original method may be called relatively the "*slow*" method. The "*sudden*" method of cooling possesses one great advantage over the "*slow*" method, viz., that it enables the temperature to which the gas is cooled to be determined much more accurately; for when the tester is surrounded by the cold liquid which is kept vigorously stirred by a small rotating screw, the temperature of the liquid rapidly rises six or seven degrees, and then remains nearly constant, rising only a degree or so per minute. With the "*slow*" method of cooling the mean of the initial and final temperatures (which differed by several degrees) has to be taken as the temperature to which the gas is cooled, an assumption which is perhaps hardly justifiable. But with the "*sudden*" method the gas is not admitted into the cooled evacuated tester until the temperature of the latter has become practically constant. Thus, by this

new method, any given experiment can be repeated time after time with the certainty of always dealing with the same temperature to within half a degree. Consequently the results obtained by this method are much more consistent than those obtained by the original "slow" method.

The temperature of the cooled petroleum ether was given by a pentane thermometer reading down to the temperature of liquid air. The thermometer is correct at 0° and -190° but is incorrect at intermediate temperatures, having a maximum error of 12° at -100° . The temperatures therefore given in the previous paper, especially those for CO_2 , require correction. In the present paper corrected temperatures are given.

Comparison of the Effects obtained in Air by the "Sudden" and "Slow" Methods of Cooling.

The air was drawn from outside through potassium permanganate, soda lime, P_2O_5 and a spiral six feet long immersed in liquid air and then through a plug of cotton wool.

The following table shows the effects obtained at different temperatures by the two methods:—

TABLE I.
(TESTER X. Vol. 3 c.c.)

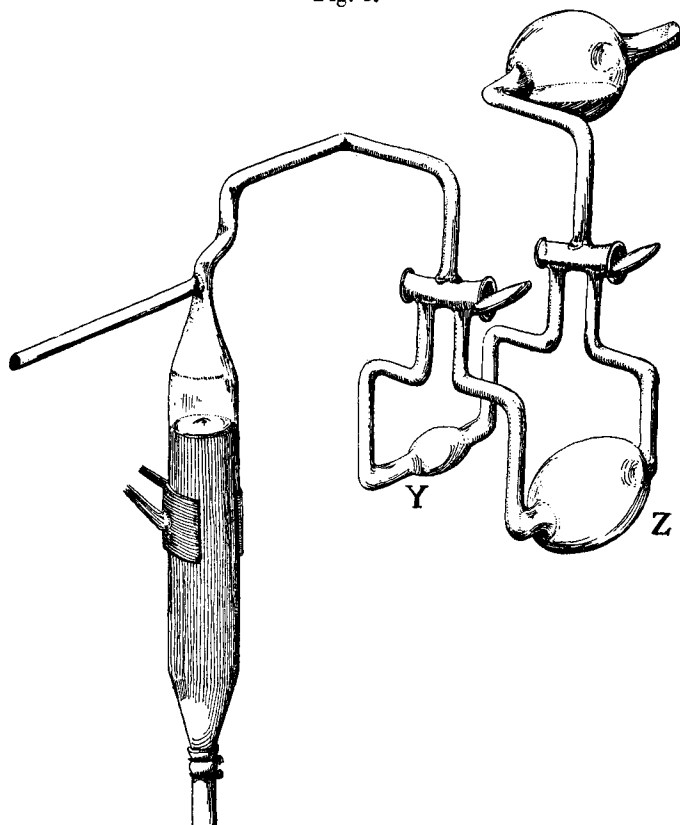
Temperature.	"Sudden" Method.	"Slow" Method.
-126°C.	0	0
-131°C.	Few drops.	0
-135°	Fair shower.	0
-140°	Good shower.	0
-145°	Heavy shower.	Fair shower.
-190°	Tinted rain-cloud.	Rain cloud.

The above table illustrates two facts:—*The more sudden the cooling the higher is the "nucleating temperature" and the larger is the number of nuclei produced at any given temperature.*

In the course of the experiments it was noticed that the values of the "nucleating temperatures" obtained depended somewhat upon the shape and size of the tester used. In order to investigate this effect systematically, the double

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tester shown in fig. 3 was made. Y had a volume of 6 c.c. and Z of 36 c.c. The following table gives the results
Fig. 3.



obtained with the apparatus in the case of air purified as described above.

TABLE II.

Temperature.	TESTER Y. 6 c.c.	TESTER Z. 36 c.c.
-75° C.	0.	0.
-80°	0.	Several drops.
-86°	0.	Fair shower.
-92°	0.	Heavy shower.
-97°	Several drops.	Very heavy shower.
-102°	Good shower.	
-107°	Heavy shower.	

Comparing this table with Table I. it will be noticed that the "nucleating temperature" for the spiral tester X of 3 c.c. and for the testers Y and Z are respectively -131° , -97° , -80° . It will be noticed that there is a considerable difference between the nucleating temperatures obtained with testers X and Y while there is a much smaller difference between the values obtained for testers Y and Z, although in the latter case the ratio of volumes is 6:1 whereas in the former only 2:1. Now the internal diameter of the tube forming tester Y was 7 mm. while that of the tube forming the spiral tester X was only 3 mm. The rush of the gas into X is therefore not nearly so sudden as into the wider tube Y. On the other hand since Y and Z are both wide the difference in the rate at which the gas rushes into them will not be so marked. The above variations are therefore due, we think, not so much to the differences in the volumes of gas cooled as to variations in suddenness of cooling due to differences in the size and shape of the testers.

The different effects obtained by the "slow" and "sudden" methods of cooling, as illustrated by Table I., naturally suggested trying a very slow rate of cooling. We used the following method to cool the gas very slowly right down to the temperature of liquid air.

The tester X with tap M open (*see* fig. 2) was enclosed in a stout brass box, but not actually in contact with it. Through the lid of the box passed a thermometer, and a propeller for stirring up the air inside. By surrounding the box with liquid air the temperature fell very slowly until it became almost stationary at -152° . The box was then quickly removed and replaced by a vessel of liquid air. The whole process took about twenty minutes. The result obtained was *a few drops*, practically a *no effect*, whereas by the ordinary "slow" method a rain cloud was obtained (*see* Table I.). In all probability the few drops actually obtained were due to the more rapid fall of temperature from -152° to -190° .

II. THE EFFECT IN PURE GASES.

Carbon Dioxide.

In the first paper we mentioned that the effect is much more marked in carbon dioxide when some of the gas is actually solidified during the cooling process, and suggested that the nuclei are produced, not while the gas is approaching the solid state, but while subliming from the solid back

again into the gaseous condition. In order to settle this point, further experiments have since been carried out on CO_2 .

The gas was prepared in two ways. In the first method it was obtained by heating pure sodium bicarbonate. It was then passed through calcium chloride, P_2O_5 , a tight plug of cotton-wool, and finally solidified in a glass tube surrounded by a tall Dewar vessel containing liquid air. When a quantity of CO_2 was required the liquid-air vessel was lowered, and after the desired amount had sublimed the flow of gas was checked by replacing the Dewar vessel. The tube containing the solid CO_2 formed therefore a very convenient gas-holder of large capacity. On its way from this gas-holder to the apparatus the gas passed through a plug of cotton-wool.

In the second method, the gas was obtained direct from the steel tubes in which it is supplied commercially and purified and condensed as before. The CO_2 obtained by these two methods gave the same results.

It was found that the gas could be cooled to any temperature not lower than its condensing point, both by the "sudden" and "slow" methods, without a single nucleus being produced. (By the "sudden" method the gas could be cooled with certainty to within a degree of its condensing point.) As the expansions used for the detection of the nuclei (where not otherwise stated) were about 1.10 some expansions nearly large enough to catch the ions in CO_2 were tried, but with the same result. This proves that for CO_2 (in contradistinction to air) no nuclei at all are produced when the gas is suddenly cooled right down to its condensing point.

It was found, however, that when condensation actually took place and the condensed gas was allowed to sublime, nuclei were present and their number increased with the amount of CO_2 which had been condensed. The nuclei obtained when CO_2 sublimates are considerably bigger than those obtained by cooling air or oxygen. The slightest supersaturation in the expansion apparatus caused by the adjusting of the pressure-drop preparatory to the expansion, brings down large numbers, but if care be taken to obviate the slightest fall in pressure, no drops are seen until an expansion is actually made. This means that the nuclei produced on the sublimation of the solid gas are bigger than those produced in air, but the fact that a certain degree of supersaturation (though small) is needed to initiate condensation on them proves them to be entirely different in character from that class of "chemical

nuclei" (such as those produced by intense ultra-violet light) in which clouds are formed without any supersaturation at all.

Ethylene.

Ethylene was prepared by the action of pure alcohol upon syrupy phosphoric acid and was passed through a condenser in ice, a strong solution of caustic potash, concentrated sulphuric acid, and P_2O_5 . It was then condensed in the tube as described in the section on CO_2 . After this liquefied gas had been allowed to boil under reduced pressure for a short time to remove any air or carbon monoxide, a quantity was distilled over into a second evacuated tube surrounded by liquid air until two-thirds of the liquid ethylene in the first tube had evaporated, the remaining third being rejected. Thus the second tube (our gas-holder for these experiments) contained ethylene of a high degree of purity.

The following summarizes the effects obtained :—

- (1) The gas which comes off liquid ethylene is quite nuclei-free.
- (2) No nuclei are produced in ethylene when cooled either by the "sudden" or the "slow" methods. The temperatures tried were -95° , -110° , -145° , and -190° , condensation taking place at the last three temperatures.

Thus there is no "nucleating temperature" for ethylene.

Methane.

Methane was prepared by heating sodium acetate with soda lime. The gas was passed through caustic potash, strong sulphuric acid, condensed and distilled as in the case of ethylene.

The following results were obtained :—

- (1) The gas which comes off liquid methane is nuclei-free.
- (2) Table III. gives the results obtained in methane by the "sudden" method of cooling.

TABLE III.

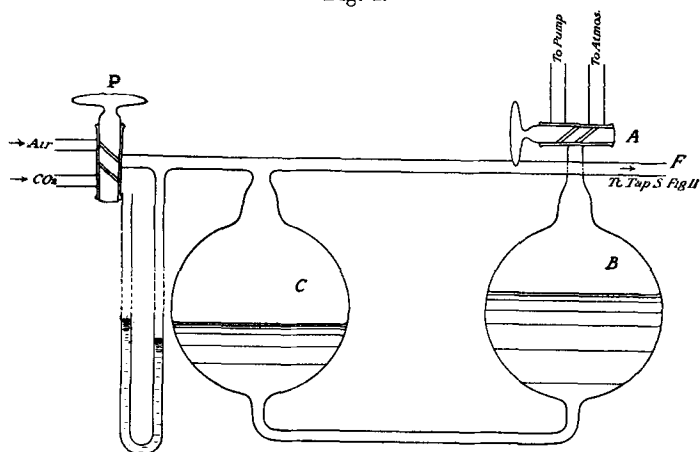
Temperature.	Effect. TESTER Y.
-97° C.	0.
-102°	Few drops.
-107°	Thin shower.
-112°	Good shower.
-131°	Tinted cloud.

Comparing the above with Table II. it will be seen that the effects obtained in methane are very similar to those obtained in air.

III. THE EFFECT IN MIXTURES.

In the hope of getting further light on the origin of the nuclei we performed a series of experiments on mixtures of gases of varying proportions. Three mixtures were tried, viz., air and carbon dioxide, air and ethylene, and air and water-vapour. The apparatus shown in fig. 4 was devised to mix the gases in known proportions.

Fig. 4.



The apparatus consists of two large glass globes of $1\frac{1}{2}$ litres capacity connected together by a glass tube. The tube F leads to tap S in fig. 2. Enough concentrated sulphuric acid is introduced to fill one globe. By means of a three-way tap A the globe B can be connected to a water-pump or to the atmosphere as desired. The mixing of the gases is effected thus:—The globe B is connected to the pump and the sulphuric acid is drawn into it to within a centimetre of the tap, which is then closed. Globe C is now exhausted through the tap D' (see fig. 2) to a pressure of about 4 cm. and air let in through P until the pressure falls a definite amount. Carbon dioxide is then admitted and, finally, more air until the pressure is atmospheric. The proportions of the constituents are determined from their respective partial pressures. Some thirty minutes are taken over this process to allow the gases to mix thoroughly. In order to diminish any

inaccuracy in the estimation of the composition of the mixture due to the 4 cms. of gas originally in the globe, it is once more exhausted and the gases mixed as before. The results obtained show that this precaution was unnecessary as the effects change but slowly with the composition of the mixture. The latter could be drawn into the apparatus (see fig. 2) at approximately atmospheric pressure by connecting the globe B to the atmosphere through the tap A. About twenty tests could be performed with the mixture before the supply in the globe C became exhausted. By means of a side path (not shown) pure air could be drawn into the apparatus for purposes of comparison.

Air and Carbon Dioxide.

The following table summarizes the results obtained in mixtures of air and carbon dioxide.

TABLE IV.
"Sudden" Method of Cooling.

Temperature.	Pure Air.	5 per cent. CO ₂ .	50 per cent. CO ₂ .
— 86° C.	0	0	0
— 92 	0	0	Fair shower.
— 96 	0	0	Good shower.
—127 	Few drops.	Few drops.	
—128 	Thin shower.	Thin shower.	
—190 	Tinted cloud.	Tinted cloud.	

It will be seen from the above table that the effects in pure air and air mixed with 5 per cent. of CO₂ are indistinguishable both in respect to the value of the "nucleating temperature" and to the magnitude of the effects obtained.

In the above experiments the mixture was maintained at a pressure of 80 cms. Thus the partial pressure of the CO₂ in the 50 per cent. mixture at atmospheric temperature was 40 cms. At this pressure the condensing temperature is approximately —85°; on cooling down, however, the partial pressure of the CO₂ when near the condensing point would be less than 40 cms., and therefore its condensing temperature would be somewhat below —85°. Now from the above table it is seen that the effect in the 50 per cent. mixture starts somewhere between —86° and —92°. On making allowance for the reduced partial pressure, it is seen that CO₂ in the

mixture behaves just the same as if the air were absent, the nuclei being produced only when condensation occurs.

The same result is borne out by experiments performed with a mixture containing 90 per cent. of CO_2 .

That the effects in pure air and air mixed with 5 per cent. of CO_2 are practically indistinguishable is sufficiently accounted for by the fact that only very few nuclei would in any case be produced by the complete condensation and subsequent sublimation of the small quantity of CO_2 present in this mixture.

Air and Ethylene.

As pure ethylene itself gives no effect at all when cooled to every temperature we have tried, the effect in air mixed with ethylene was investigated.

The following table shows the results obtained in three different mixtures of air and ethylene.

TABLE V.

Temp.	Air.	5 per cent. Ethylene.	50 per cent. Ethylene.	90 per cent. Ethylene.
-125° C. ...	0	0		
-127 ...	0	Few drops.		
-128 ...	Very thin shower.	Thin shower.	0	0
-131 ...	Thin shower.	Good shower.	0
-133 ...	Good shower.	Good shower.	Fair shower.	Very thin shower.
-143 ...	Heavy shower.	Heavy shower.
-190 ...	Tinted rain-cloud.	Tinted rain-cloud.	Tinted rain-cloud.

Here again it will be noticed that the effects in pure air and in air mixed with 5 per cent. of ethylene are practically identical. The "nucleating temperature" in the mixture, it is true, is a few degrees higher than for pure air, but the difference is not sufficiently marked for any great importance to be attached to it. On the other hand, the results in a 50 per cent. mixture are readily understood, the effects obtained being simply those which would be obtained in air at a pressure equal to its partial pressure in the mixture.

The nucleating temperature in the 90 per cent. mixture bears out the same view. It will be seen, however, from the table that when the 90 per cent. mixture is cooled by liquid air just as many nuclei were produced as in the case of pure

air. Now considering the fact that ethylene itself is ineffective in the production of nuclei and the total quantity of air in this mixture is small, this is somewhat surprising. This may possibly be accounted for by the fact, that when the tap between the reservoir and the evacuated tester in liquid air is opened, the instantaneous condensation of the ethylene that takes place carries the air so rapidly into the tester that the latter is subjected to an extremely sudden fall of temperature.

Water-Vapour in Air and CO₂.

In the experiments described in the previous paper we had taken great care to obtain the gases quite dry. Since then we have examined the effect in wet gases.

An apparatus was devised in which the gas after having been thoroughly dried could be drawn through either of two paths before entering the reservoir and tester. In one path was an arrangement by which the gas bubbled through water, thus saturating it with water-vapour. With dry air the effects started at about -129° . With wet air we obtained a very small effect (never more than a "few drops") at temperatures between -122° and -129° . At temperatures below the "nucleating temperatures" the effects in dry and wet air were identical.

With wet CO₂ we obtained a small effect (a "very thin shower") at some five or seven degrees above the condensing-point, whereas with dry CO₂ no effects were obtained unless condensation occurred, as has been described above. But below the condensing temperature the effects in wet and dry CO₂ were indistinguishable.

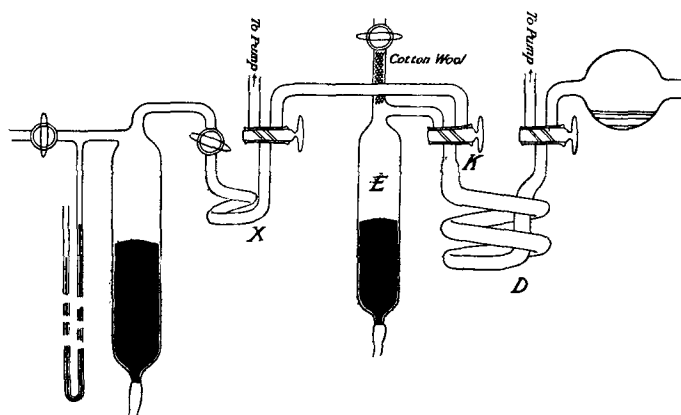
IV. THE PERSISTENCY OF THE NUCLEI AT DIFFERENT TEMPERATURES.

Air Nuclei.

It had often been noticed that when air containing nuclei produced by sudden cooling was left over night in the tester, no effect was obtained on passing it into the cloud-chamber on the following morning, showing that the nuclei had in some way or other disappeared. On making a similar experiment with dusty air from the room there was only a small diminution in the effect in the same interval of time. This led to a more thorough investigation of the persistency of the nuclei. Several forms of apparatus were tried, but the

form found to be most suitable for these experiments is shown in fig. 5.

Fig. 5.



The tester used was the spiral tester of volume 3 c. c. The nuclei were produced in this by the "sudden" method of cooling, the temperature being that of liquid air. They were then driven into the evacuated spiral "oven" D of capacity 35 c.c., where they were kept for different lengths of time and at different temperatures. From this "oven" they were finally driven into the cloud-chamber by means of filtered air from the auxiliary reservoir E.

The following table illustrates the rate at which the air nuclei disappear at atmospheric temperature and pressure.

TABLE VI.

Length of Time in the "Oven."	Effect obtained.
1 minute.	Tinted rain-cloud,
3 minutes.	Heavy shower.
10 "	Thin shower.
20 "	Several drops.
14 hours.	0

We next compared the persistency of the nuclei at different temperatures. The "oven" could be maintained at any desired temperature up to 200° C. by hot glycerine. In order to have initially in the "oven" always the same number of nuclei the nucleated gas was driven into it at

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atmospheric temperature, and immediately the tap K was closed, the "oven" was surrounded by hot glycerine for a definite length of time. A similar experiment was then made in which the "oven" was kept at atmospheric temperature for the same time. Before admitting into the cloud-chamber, the gas in the "oven" was allowed one minute in which to regain atmospheric temperature.

Table VII. compares the persistency of air nuclei at different temperatures.

TABLE VII.

Time and Temperature in "Oven."	Effect.	Time and Temperature in "Oven."	Effect.
2 min. at 15°.....	Heavy shower.	1 min. at 100°. } 1 min. at 15°. }	Fair shower.
4 min. at 15°.....	Good shower.	3 min. at 100°. } 1 min. at 15°. }	Very thin shower.
9 min. at 15°.....	Few drops.	8 min. at 100°. } 1 min. at 15°. }	0

Time and Temperature in "Oven."	Effect.
1 min. at 185°. } 1 min. at 15°. }	Fair shower.
2 min. at 185°. } 2 min. at 15°. }	0

The above table shows clearly that keeping the nuclei at a high temperature aids their disappearance. This suggested that the nuclei would be still more persistent if kept at a low temperature. This was verified, for it was found that after thirty minutes at -75° a fair shower was obtained which is greater than the effect obtained after a much shorter period at 15° (see Table VI.).

Thus raised the interesting question as to whether the nuclei would persist indefinitely if kept at a temperature at which they were produced. To investigate this point an experiment was carried out with tester Z (see fig. 3). When the nuclei were produced by the "sudden" method at the temperature of liquid air, the effect obtained a minute and a half later was a thick white fog. On producing the nuclei in the same way, but keeping them for two hours in the tester

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surrounded by liquid air, the effect now obtained was only a "fair shower"; this shows that, provided a sufficiently long time be given, the nuclei disappear even at the temperature of production.

Carbon Dioxide Nuclei.

Table VIII. shows the rate of disappearance of CO₂ nuclei at 15° and 80 cms. pressure, the nuclei having been produced by the sublimation of CO₂ solidified by liquid air.

TABLE VIII.

Time in "Oven" at 15°.	Effect.
20 secs.	Tinted rain-cloud.
3 mins.	Rain cloud.
10 "	Very heavy shower.
30 "	Good shower.

The following Table IX. shows the effect of high temperature upon the life of these nuclei. In this case, the nucleated CO₂ was driven into the "oven" at a pressure of 55 cms. The showers are therefore not so dense as those given in Table VIII.

TABLE IX.

Time and Temperature in "Oven."	Effect.	Time and Temperature in "Oven."	Effect.
1 min. at 185° } 1½ " 15° }	Heavy shower.	2½ min. at 15°	Dense shower.
3 " 185° } 1½ " 15° }	Fair shower.	4½ " 15°	Heavy shower.
10 " 185° } 1½ " 15° }	Very thin shower.	11½ " 15°	Good shower.

Evidently the disappearance of the CO₂ nuclei is also aided by high temperature. Comparing Table VIII. with Table VI. we see that the CO₂ nuclei are somewhat more persistent than air nuclei.

V. ELECTRICAL CONDITION OF THE NUCLEI.

Experiments were made to see if the nuclei were electrically charged. Nucleated air produced by cooling to the temperature of liquid air was passed into a chamber in which it could

be subjected to an intense electric field. This chamber was a glass tube about 10 cms. long and 3 cms. in diameter. Inside was a closely fitting brass tube of nearly the same length, which in turn surrounded a thick brass rod coaxial with it. There was thus left an annular space about 5 mm. wide between the brass tube and the central rod. Most of the gas driven into the tube was located in this space. After remaining in this space for one minute under the action of different electric fields, the nucleated air was driven into the cloud-chamber. The effect was found to be the same whether the electrodes were both earthed or at potential-differences of 230, 1000, or 4000 volts.

This proves the nuclei to be uncharged.

VI. DISCUSSION OF RESULTS.

The additional investigations published in this paper have not furnished evidence necessitating a change in the views expressed in the previous paper. Still much remains obscure and difficult to account for completely. We restate our explanation of the effects as follows:—

When the temperature of the gas falls sufficiently, and *not too slowly*, molecular aggregations are formed, most probably of those slowly moving molecules whose kinetic energy is less than their mutual potential energy. On the kinetic theory, this means of course that the aggregations approximate more to the liquid phase than to the gaseous. Possibly the effects may be regarded as pointing to incipient liquefaction taking place in the gas at a temperature well above the real liquefying temperature.

The number of molecular aggregations is increased to a remarkable degree by increasing the suddenness of cooling. We find this difficult to explain, possibly it may be connected with the *irreversibility* of the phenomenon as evidenced by their persistency.

It has already been stated that the nuclei are of considerable size. This does not necessarily mean that smaller nuclei are not produced under the same circumstances, for such aggregations might be produced but, owing to smaller stability, have disappeared before the expansion can be made.

The more rapid disappearance of the nuclei at higher temperatures is readily explained by the more vigorous bombardment of the aggregations by the molecules of the heated gas.

The results in CO_2 are interesting as they suggest a fundamental difference between evaporation from the liquid

phase and sublimation from the solid. We have found that the gas evolved from liquid air, oxygen, ethylene, methane is nuclei-free, confirming the ordinary view that the evaporation of a liquid consists in the escape of *separate molecules*. But the fact that a mass of solid CO_2 (previously condensed in a perfectly dust-free state) continues to give off gas containing enormous numbers of nuclei until the whole mass has disappeared, suggests that the sublimation of solid CO_2 (and possibly of other substances which can pass from the solid direct into the gaseous phase) consists in the escape of separate molecules *together with numerous molecular aggregations*.

We will in conclusion meet some possible objections to the above views. As the effects obtained are larger when the gas is allowed to rush into the cooled evacuated chamber it might be urged that the nuclei are simply dust particles dislodged from the walls of the vessel by the sudden rush of gas. This view, however, is quite untenable from the following considerations:—(1) The effect shows no signs at all of diminution however often the experiments are made with any particular tester. (2) No effect is obtained when the gas rushing into the evacuated tester is pure ethylene, whereas a considerable effect is obtained when the ethylene contains a small percentage of air. (3) The nuclei are rapidly destroyed at a temperature of about 200°C .

Nor can it be argued that the nuclei are due to insufficient drying of the gases, as there is very little difference between the behaviour of wet gases and of those dried with the utmost precautions.

Then again it might be urged that the nuclei are due to the presence of some impurities in the gases. This point was discussed in the previous paper. If the impurity be, let us imagine, CO_2 it is not likely that the effects in purified air and in air mixed with five per cent. of CO_2 would be indistinguishable as was found to be the case (see Table IV.).

Supposing on the other hand the impurity to be some gas only slightly more easily liquefied than air, we meet with the same difficulty in accounting for the production of the nuclei in this impurity as we do in the case of air. If the effects are due to some impurity, then the only gas we obtained pure must have been ethylene. The precautions which we have taken, however, to obtain pure gases, especially in the case of oxygen and air, render this "impurity" explanation highly improbable, certainly not more probable than the view we have expressed above.

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