# THE DISAPPEARANCE OF SMOKE IN A CONFINED SPACE.

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Using the Tyndallmeter already described,[1] the gradual disappearance of smokes in a confined space has been investigated. The work was carried out by the Dispersoid Section, Research Division, Chemical Warfare Service, U. S. A.[2]

**Theoretical.**—The problem at hand was to determine the relation between the rate of disappearance of a smoke enclosed in a confined space and such factors as the rate of stirring of the smoke, the concentration of the smoke, and the size of its particles.

The rate of disappearance was followed by means of the Tyndallmeter. It has already been shown[3] that the concentration of a smoke is proportional to its Tyndallmeter reading, but the relation between Tyndallmeter reading and size of particles has not yet been determined.

For very small particles it seems certain that the strength of the Tyndall beam will follow Lord Rayleigh's theoretical law and thus be proportional to the number of particles, $n$, present per cubic centimeter and to the sixth power of their diameter, $d^6$; for large enough particles, on the other hand, it seems reasonable to expect that the strength of the Tyndall beam will be proportional to the number of particles per cubic centimeter, $n$, and to their area of reflecting surface or to $d^2$. Under these circumstances we can write as our limiting forms for the strength of Tyndall beam T

$$\mathrm{T} = k\,n\,d^6 \qquad \text{for small particles} \tag{1}$$

$$\mathrm{T} = k'\,n\,d^2 \qquad \text{for large particles} \tag{2}$$

where $k$ and $k'$ are constants.

Noting that the concentration of material $c$ is proportional to $nd^3$ we may write (1) and (2) in the forms:

$$\mathrm{T} = k\,c\,d^3 \tag{1}$$

$$\mathrm{T} = k'c/d \tag{2}$$

In accordance with the above explanation it is evident that strength of Tyndall beam will vary in general both with the concentration of the smoke and with the size of its particles, and in measuring the rate of disappearance of a smoke with the help of a Tyndallmeter we must be prepared to find that the disappearance depends both on actual changes in concentration and on the coagulation of particles as well.

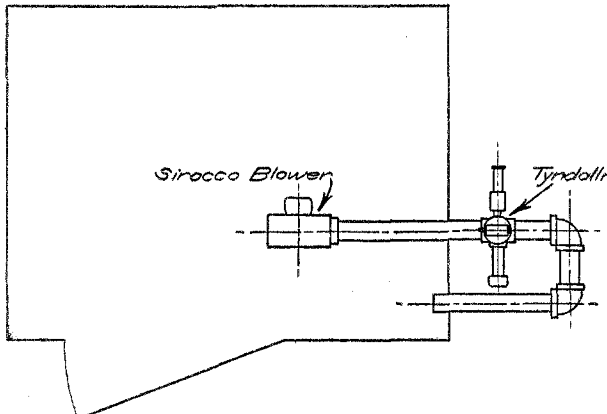
**The Smoke Box.**—The experiments to be described were carried out in a metal box having a volume of approximately one cubic meter. The

[1] THIS JOURNAL, 41, 297 (1919).

[2] This article has been approved for publication by Major-General William L. Sibert, Director of Chemical Warfare Service, U. S. A.

[3] THIS JOURNAL, 41, 300 (1919).

smokes were set up inside the box either by explosive or thermal action, and then examined at intervals with the Tyndallmeter. The set-up is shown diagrammatically in plan in Fig. 1. The sample of smoke to be examined is circulated through the Tyndallmeter by a No. 00 electrically driven Sirocco blower manufactured by the American Blower Co.




SET UP FOR EXAMINATION OF SMOKES

Fig. 1.

**Effect of Stirring on Rate of Disappearance.**—The disappearance of a smoke in a confined chamber is markedly increased by stirring the smoke. This undoubtedly arises, at least in large measure, from the fact that the stirring of the smoke brings it in contact with the walls of the chamber where the particles stick.

The smoke-producing substances experimented on were acetanilide, benzoic acid and rosin. They were placed in gelatine capsules surrounding a Dupont blasting cap and then detonated inside the box. Their smoke-producing power is in the order listed, acetanilide being a very poor smoke-producer and rosin a very good one. In the case of acetanilide and benzoic acid one gram of the material was used with a No. 8 blasting cap (containing two grams fulminate). Only one-half gram of rosin was used with a No. 6 blasting cap (containing one gram fulminate).

In order to determine the effect of stirring, experiments were made on each substance running the Sirocco blower (1) continuously at a slow rate, (2) continuously at a high rate, (3) only when the reading was being taken, (4) only when the reading was being taken and not starting readings until after the lapse of one hour.

The data on the three substances are presented graphically in Figs. 2, 3 and 4, the times being plotted as abscissas and the Tyndallmeter readings as ordinates. It will be seen from Curves 1 and 2 on each plot that the more rapid rate of stirring leads to a much more rapid rate of smoke disappearance, and from Curves 1 and 3 that the continuous stirring

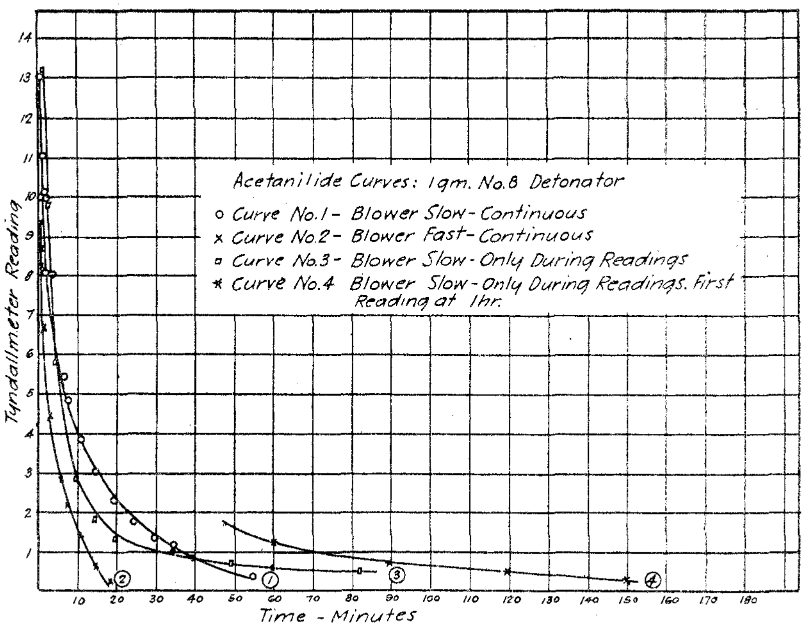

Acetanilide Curves: 1gm. No.8 Detonator
o Curve No.1 - Blower Slow - Continuous
x Curve No.2 - Blower Fast - Continuous
▫ Curve No.3 - Blower Slow - Only During Readings
* Curve No.4 Blower Slow - Only During Readings. First Reading at 1hr.
Tyndallmeter Reading
Time - Minutes

Fig. 2.

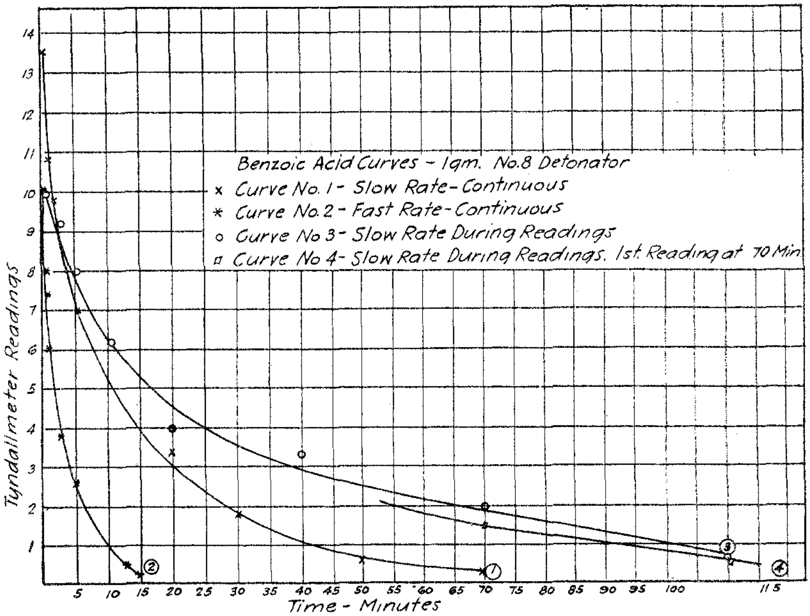

Benzoic Acid Curves - 1gm. No.8 Detonator
x Curve No. 1 - Slow Rate - Continuous
* Curve No.2 - Fast Rate - Continuous
o Curve No 3 - Slow Rate During Readings
▫ Curve No 4 - Slow Rate During Readings. 1st Reading at 70 Min
Tyndallmeter Readings
Time - Minutes

Fig. 3.

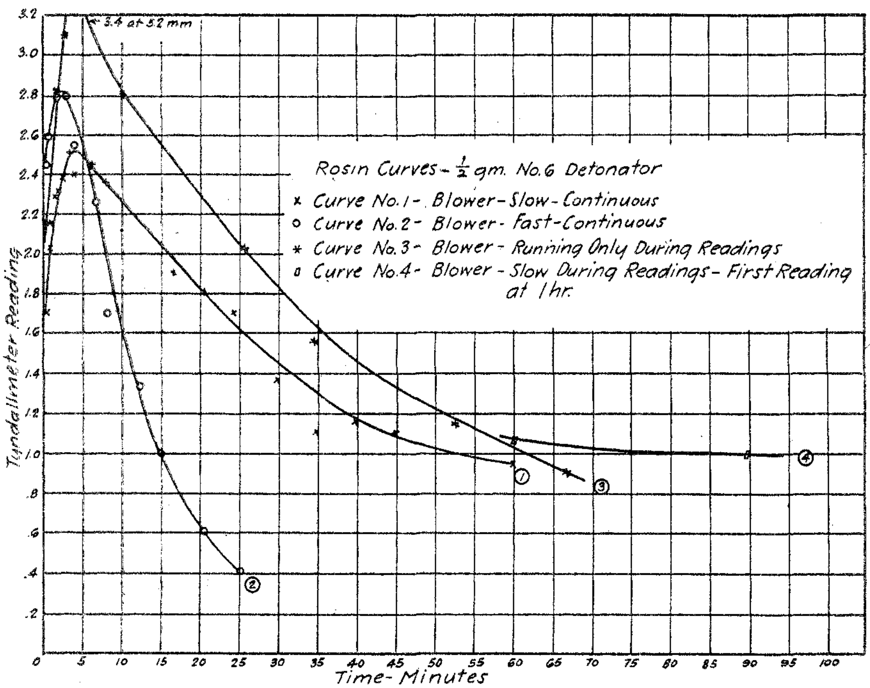



Fig. 4.

leads to a more rapid disappearance than an occasional stirring at the time of reading the sample. By comparing Curves 3 and 4 it will be seen that within the limits of error the rate of disappearance is not appreciably affected by an occasional stirring just at the time of reading the sample.

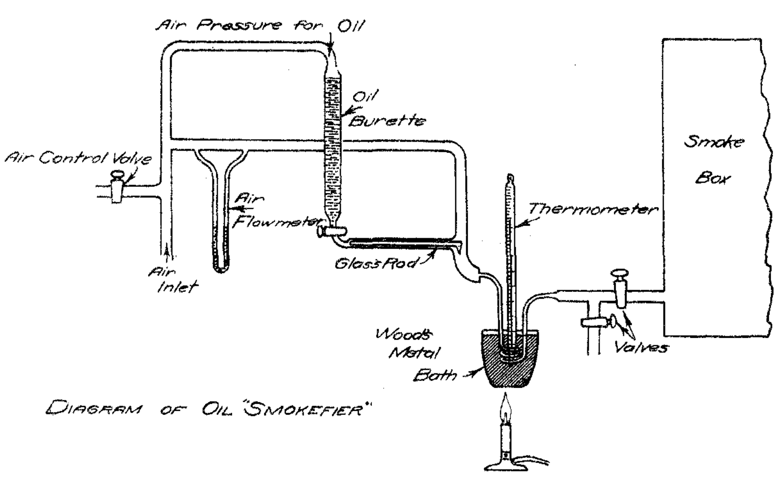



Fig. 5.

In looking over the figures a few discrepancies will be noticed. Thus in Fig. 2 Curve 3 falls below Curve 1 for a part of its course. With the somewhat crude method of smoke production, however, very precise results are not to be expected.

**Effect of Concentration on Rate of Disappearance.**—In order to determine the effect of smoke concentration on rate of disappearance, the apparatus shown in Fig. 5 was arranged by which different quantities of oil could be dispersed in the form of smoke by heating in a stream of air and then introduced into the box.

The oil used was petroleum oil commercially known as No. 2 Polarine and was contained in a 25 cc. buret, so arranged that it could be forced into the system at a known rate, which could be easily varied from 0.2 to 2 cc. per minute. Air was supplied at a constant rate of 15 liters per minute and the mixture of oil and air was carried into a copper spiral made of $^1/_8''$ (inside diameter) tubing which was immersed in a Wood's metal bath kept at a temperature of 350° C. by means of a Bunsen burner.

In using the apparatus, the smoke produced was first allowed to escape through a valve into the room and not introduced into the smoke box until it was uniform in quality. With the help of the buret a known quantity of oil could then be introduced into the box in the form of smoke. The probable error in judging smoke concentration by this means is about

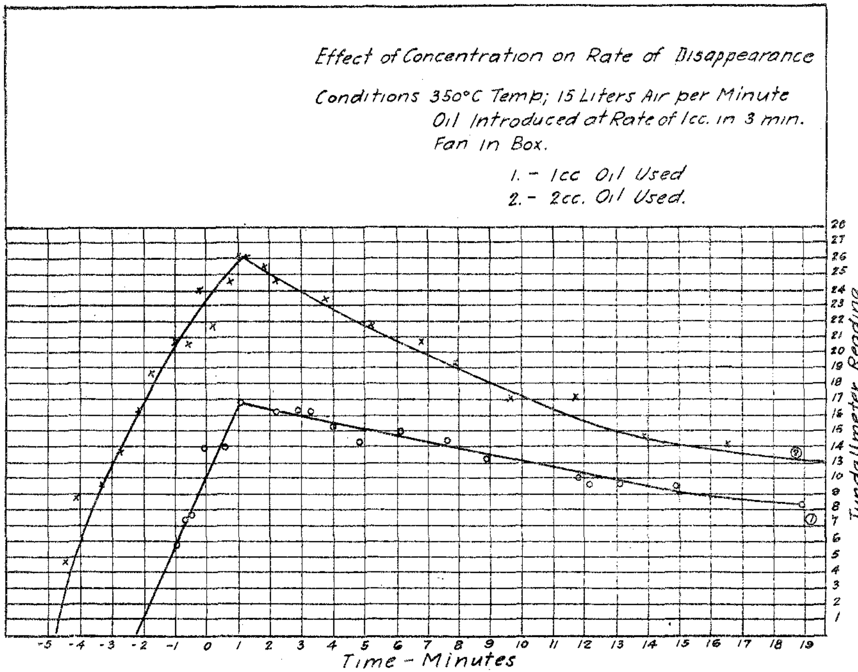



Fig. 6.

10% when 1 cc. of oil was passed in in one minute. With smaller amounts and faster rates this error is increased while with larger amounts and slower rates it is much lower.

The disappearance of the smoke was followed by means of a Tyndallmeter arranged with a Sirocco blower as described in the previous experiments, the blower running continuously throughout the experiment.

The plot in Fig. 6 gives a typical example of the effect of increased concentration on rate of smoke disappearance, the times being plotted as abscissas and Tyndallmeter readings as ordinates. In both experiments recorded the oil was "smokefied" under exactly the same conditions, but in Expt. 2 twice as much oil was introduced as in Expt. 1. There was an electric fan in the box to assist in maintaining homogeneity.

The important thing to notice is that the higher the concentration the greater the rate of disappearance. This is shown not only by the greater steepness with which Curve 2 falls off but also by the fact that its Tyndallmeter reading never reaches a value twice as great as in Expt. 1, but actually shows a bending over before the oil has all been introduced.

**Effect of Size of Particle on Rate of Disappearance.**—With the apparatus just described, it was possible to obtain smokes with small or large particles according to the rate at which the oil was fed into the apparatus,

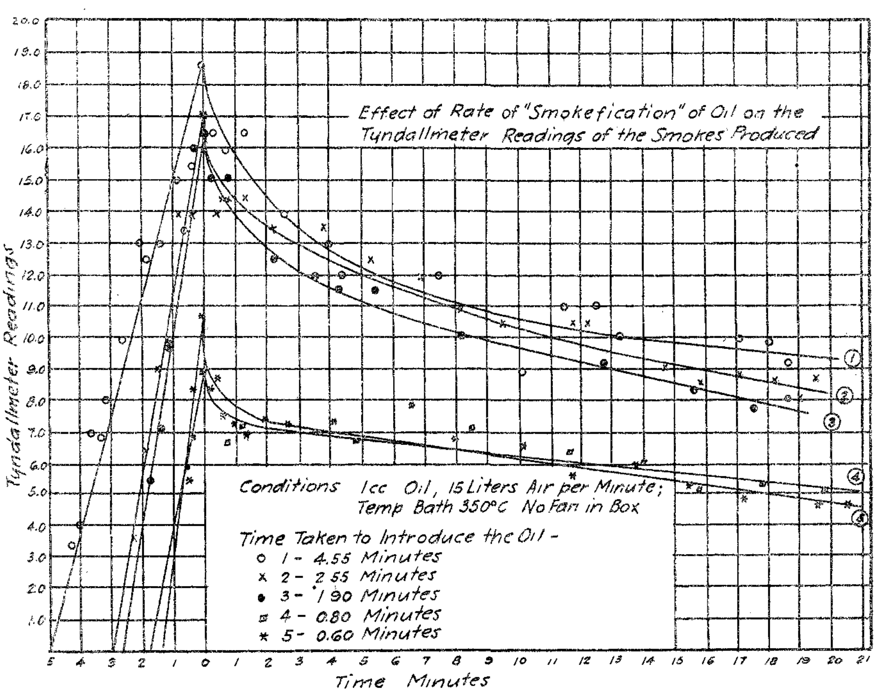



Fig. 7.

keeping the stream of air constant. If the oil was fed slowly into the apparatus we obtained a smoke with fine particles as shown by its very blue color, and if the oil was fed in rapidly we obtained a very white smoke, indicating large particles.

In order to test the effect of different sized particles, the experiments shown in the plot, Fig. 7, were carried out. The same amount of oil, one cc., was used, but it was forced in at different rates. The first fact to be noticed is that the slower the rate at which the oil is forced in (*i. e.*, the smaller the particles) the higher the Tyndallmeter reading. This seems reasonably good evidence that with a given concentration of smoke, an increased degree of dispersion leads to higher Tyndallmeter readings, owing to the increased reflecting surface. This is more nearly in accord with our Equation 2,

$$T = k' c/d$$

than with Equation 1,

$$T = k c d^3,$$

which was derived by Lord Rayleigh for *infinitely* small particles. Further evidence on this point will be presented at a later time.

As to the effect of size of particle on rate of disappearance, the general slope of the disappearance curves seems steeper for small particles than for large ones. This is presumably due to the fact that the fine particles with their greater velocity of diffusion come in contact with each other and coalesce more frequently.

**Maximum Smoke Density Obtainable.**—The fact that smoke disappears more rapidly the higher the concentration and the higher the degree of subdivision indicates that it would be impossible to maintain a high concentration of very fine particles. In order to test this, the experiments shown in the plot, Fig. 8, were carried out. In them the oil was run in at different rates and the maximum obtainable Tyndallmeter reading determined.

In Expt. 1, the oil was introduced at the rate of 0.25 cc. per minute and a maximum reading of about 35 obtained. In accordance with our explanation, higher readings than 35 cannot be obtained since the rate of disappearance increases with concentration.

In Expt. 2 the oil was run in at a faster rate of 1.12 cc. per minute. This would result in larger particles, which in accordance with our theory would tend to coagulate less rapidly, owing to their slower rate of diffusion, and also, of course, to the fact that the particles are further apart for a given concentration of material. Under these conditions it was possible to obtain a maximum Tyndallmeter reading of about 50.

The interesting see-saw nature of the curves obtained should be noticed. This was probably not due to error in reading since the points fell quite

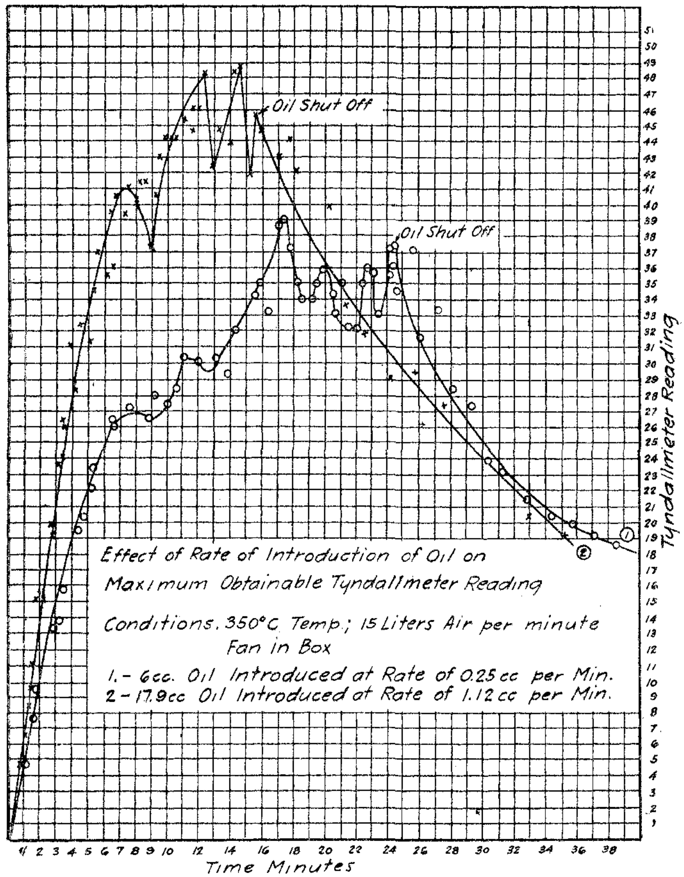



Fig. 8.

consistently on the curve. It should also be noticed that the fan in the box prevented any lack of homogeneity in the smoke.

## Summary.

When a smoke is set up in a confined space it gradually disappears, owing to coagulation, to settling and to the diffusion of the particles to the walls where they stick. In the experiments described in the preceding article the rate of disappearance of smokes in a one cubic meter box was followed by means of a Tyndallmeter.

1. It was found that the rate of disappearance was markedly increased by stirring the smoke, owing presumably to the fact that it was thus brought into contact with the walls where the particles could stick.

2. By setting up smokes with the same concentration of material in grams per liter, but by methods which led to a difference in size of particles, it was shown that the finer subdivision of material led to higher

Tyndallmeter readings, owing to the greater reflecting surface of the particles.

3. It was found that the rate of disappearance of a finely divided smoke of a given concentration was greater than for a coarser smoke owing to the increased opportunity for coalescence.

4. By setting up smokes with the same size of particles but with different concentrations it was found that the rate of disappearance increases with concentration owing to the increased chance for coagulation and removal by the walls.

5. Since increased concentration and increased subdivision both lead to a higher rate of disappearance, it is impossible to raise the optical density of a smoke beyond a certain point by the introduction of further smoke material.

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## AN OSCILLATION METHOD FOR MEASURING THE SIZE OF ULTRAMICROSCOPIC PARTICLES.[1]

By P. V. Wells and R. H. Gerke.

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**Introduction.**—It is one of the familiar properties of ultramicroscopic particles that some portion of any given type are electrically charged. Moreover, it is now accepted that the charges carried by any such particles are always multiples of the elementary unit, the electron. When the particles are not ionized by some powerful agent, the charged particles form but a fraction of the whole number and most of the charged particles possess but a single electron. Compared with the number carrying one electron, in statistical work the number doubly charged is negligible. The observed motion of the particles in a given electrostatic field is thus a measure of their size.

The usual method of observing the motion of the charged particles is much improved in precision by reversing the direction of the field by means of a rotating commutator. In this way the particle is made to perform repeated oscillations, the amplitude of which may be measured with considerable precision, making possible for the first time the precise measurement of the size of a single ultramicroscopic particle.

The following paper presents some of the results obtained by this method with ultramicroscopic particles suspended in air.

**Properties of Gaseous Disperoids.**—The most important characteristic of suspensions of small particles in air is that they are not in equilibrium. The particles are continually diffusing to the surrounding walls, and collid-

[1] This paper describes part of a joint investigation by the Bureau of Standards and the Dispersoid Section, Research Division, Chemical Warfare Service, and has been approved for publication by Major-General William L. Sibert, Director of Chemical Warfare Service, U. S. A. and by S. W. Stratton, Director of the Bureau of Standards.