ASSOCIATION NEWS

REPORT OF THE MAY 24–25, 1946 MEETING, Continued

With President-elect Stage absent because of the railway strike and with President Ruth presiding, as stated in an earlier number of MOSQUITO NEWS, the program was started by President Ruth with the announcement that since Dr. Bishopp and Dr. Ginsberg (both on the morning program) were likewise absent, the entire morning session would be available for discussion of the remaining item on the morning program, namely, *The Significance of Particle Size in Sprays and in Aerosol Fogs,* and that the subject would be opened with a paper read by Dr. R. D. Glasgow, who would then lead the discussion.

Dr. Glasgow spoke informally, substantially as indicated in the manuscript submitted.

THE SIGNIFICANCE OF PARTICLE SIZE IN SPRAYS AND IN AEROSOL FOGS[1]

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Many insect pests, including mosquitoes, many fungus diseases of crop plants and of fruits, and even weeds of many kinds may be suppressed by introducing into their environment some poison or other factor that in one way or another may prevent their normal activities.

Such poisons are usually applied either dry in the form of dusts, in liquid form as sprays or mists or fogs, or as a gas; the dusts being more or less finely pulverized solids, the gaseous poisons in general being limited to use in closely sealed enclosures, and the liquid sprays or mists or fogs being distinguished, as the names indicate, by the range of droplet diameters characteristic of each.

CONTRIBUTIONS FROM THE STUDY OF "SMOKES" FOR WAR USE

While the greater effectiveness of more finely dispersed insecticide and fungicide dusts and sprays was recognized even before the recent war, our understanding of the behavior of small particles, and the development of improved mechanisms for their production and use have been tremendously advanced through special studies prompted by war needs.

[1] Many of the data given are adapted from "Clouds and Smokes" by W. E. Gibbs, and from the "Handbook of Chemistry and Physics," edited by Charles D. Hodgman.

Under war compulsion, much money and scientific effort were expended upon intensive studies of minute particles dispersed in air, and of means for the production of aerosol fogs.

These studies had various objectives. One objective, for example, was better knowledge concerning the production and behavior of, and possible defense against minute particles or "smokes" of special chemicals which would pass unchecked through the canister of a gas mask, and by producing tears or inducing a paroxysm of violent sneezing, would force the wearer to remove his mask and thus become exposed to an accompanying poison gas. An even more immediately important objective was the development of new and better, and more abundantly available sources of screening "smokes" for use especially in battle to conceal the movement of troops or of ships.

Since the dawn of history, screening smokes have been used for concealment in warfare. According to early records smoke from smudge pots, or even from incendiary conflagrations was commonly used. During the first world war, chemical "smokes" similar to those employed by sky-writers were tried. During the second world war, however, screening smokes were required in such huge quantities that neither suitable fuel, nor any appropriate chemical was available in sufficient quantity to produce them.

Early in the last war, therefore, intensive scientific study of the problem resulted in the development of several more or less similar thermal dispersion mechanisms which could produce a fog of minute oil droplets, the diameter of which (about 2/3 of a micron) was such as to give maximum dispersion of light rays in the visible spectrum, and thus provide maximum concealment.

A solid reduced to minute particles may be dispersed in air as a dust or smoke, and if insoluble may be dispersed in a liquid as a suspension. A liquid reduced to minute droplets may be dispersed in an immiscible liquid medium as an emulsion; or if relatively non-volatile, may be dispersed in air as a spray, or mist, or fog. Such a mixture of one substance suspended in another as very small particles is called a disperse system.

Within technically prescribed limits of particle size, but employed more loosely in popular discussion, where water is the dispersion medium, the disperse system is known as a *hydrosol;* and where air is the dispersion medium, the disperse system is known as an *aerosol.*

The properties and performance of such disperse systems present a very large field for study and discussion: entirely too large a field to be covered adequately in the time at our disposal this morning.

Accordingly, we shall limit our discussion, today, to some of the properties of oil droplets dispersed in air, since this phase of the larger subject appears at present to be of special interest to mosquito control workers.

ADAPTATION OF THE THERMAL AEROSOL FOG TO THE DISPERSION OF INSECTICIDES

With the appearance of the new oil-fog "smoke" generators on the battlefield in areas where mosquitoes and mosquito borne diseases were an important military problem, the question was raised why the new and powerful insecticide DDT could not be dissovled in the fog oil, and the new mechanisms given a multiple service value.

This was tried locally with encouraging success; but because the high temperature employed to vaporize the fog oil was supposed to decompose and inactivate a very considerable percentage of the DDT, and because the military screening smokes produced by these early machines would rise too high, drift too far, and deposit too sparingly for effective insect control use, further studies were started in various quarters, designed to work out more fully the properties and performance of disperse systems of the thermal aerosol fog type, and to modify the earlier military, thermal "smoke" generators, so they could be operated at lower temperatures, to produce aerosol fogs of various, and controllable droplet diameters.

THE UNIT OF MEASURE EMPOLYED IN THE DISCUSSION OF DROPLET DIAMETERS

Spray droplets, and especially the droplets of aerosol mists and fogs may be so extremely small that we must have a very small unit of measurement with which conveniently to express their diameters. Our American system of feet and inches does not provide any such conveniently usable small units of measurement. It is customary then, when discussing such small objects, to turn to the metric system of measurement, and to express the diameters, as of spray and fog droplets, in microns.

What is a Micron? (Since some of our members may not be accustomed to think in terms of metric units of measurement.)

1. A *meter* is a little more than one yard, or 39.37 inches, to be exact.
2. A *millimeter,* as the implies, is one one-thousandth (1/1000) of a meter, or about one twenty-five thousandth an inch.
3. A *micron* is one one-thousandth (1/1000) of a millimeter; one one-millionth (1/1,000,000) of a meter, or about one twenty-five thousandth (1/25,000) of an inch.

WHY IS PARTICLE SIZE SIGNIFICANT IN INSECTICIDE SPRAYS, MISTS, AND FOGS?

At the same temperature and pressure, the reactivity of a chemical, or the effectiveness of an insecticide or fungicide, increases with an increase of exposed surface; and for droplets of different diameters, the volumes are to each other as the cubes of the diameters (or "as the cubes of like dimensions") while the surfaces are to each other as the squares of the diameters.

So, for equal volumes of an oil dispersed as spray or fog, with one volume dispersed as droplets 50 microns in diameter, and an equal volume dispersed as droplets 5 microns in diameter, the diameter of the larger droplets being 10 times that of the smaller, there would be 10 times 10 times 10, or 1000 times as many of the smaller droplets, with the total surface area of the smaller droplets 10 times 10, or 100 times as great as the total surface area of the larger droplets.

Not only this, but the reactivity or effectiveness increases further with an increase in the convexity of the exposed surface; and, obviously, the surface of the droplets rapidly becomes more sharply convex, as the diameter becomes smaller and smaller.

For example: One gram (approximately one thirtieth of an ounce, or a little less than a quarter of a teaspoonful) of water falling as the large drops of a heavy rain would represent about 30 drops, each 4 millimeters or 4000 microns in diameter, and the total surface area of the 30 drops would be about 15 square centimeters; or a total surface area about equal to one side of 3 ordinary postage stamps.

As a fine drizzle, the same one gram of water would make thirty thousand droplets each 0.4 of a millimeter or 400 microns in diameter, with a total surface area of 1,500 square centimeters.

In the form of a mist, the same one gram of water would make thirty million droplets each 0.04 of a millimeter or 40 microns in diameter, with a total surface area of 150,000 square centimeters.

Again, in the form of a fog, the same 1 gram of water would make thirty billion droplets each 0.004 of a millimeter or 4 microns in diameter, with a total surface area of 15,000,000 square centimeters, or a total surface area about equal to the combined area of two average city lots, each 60x120 feet.

And finally, in the form of a cloud, the same 1 gram of water would make thirty trillion droplets each 0.0004 of a millimeter or 0.4 of a micron in diameter, with a total surface area of 1,500,000,000 square centimeters, or a total surface area of 37 acres; equivalent to an area almost a quarter of a mile square.

It may be helpful now to translate these, or similar figures into terms of distribution per unit area, for an insecticide solution applied as spray or fog.

For application from the air, some operators have come to the conclusion that 2 quarts per acre represents a practical balance between pay-load and coverage, with the concentration adjusted to give the desired quantity of insecticide per unit area.

Mechanical sprays vary widely in particle size, depending upon the pressure,

RECAPITULATION. Relation of Droplet Diameter to Number of Droplets, and to Total Surface Area.

Quantity of Water	Type Dispersion	Diameter of Droplets		Number of Droplets	Total Surface Area of Droplets
		Millimeters	Microns		
1 gram	Rain	4.0	4000	30	15 sq. cm. (3 postage stamps)
1 gram	Drizzle	0.4	400	30 thousand	1,500 sq. cm. (12 in. x 17 in.)
1 gram	Mist	0.04	40	30 million	150,000 sq. cm. (10 ft. x 14 ft.)
1 gram	Fog	0.004	4	30 billion	15,000,000 sq. cm. (2 city lots)
1 gram	Cloud	0.0004	0.4	30 trillion	1,500,000,000 sq. cm. (37 acres)

and the type of nozzle used; the droplets ranging from something like 40 or 50 microns to about 150 microns in diameter, and having an average droplet diameter for the sprays usually employed probably in the neighborhood of 100 microns.

At 2 quarts per acre:

1. With droplets 100 microns (1/250 inch) in diameter, there would be approximately 1 droplet for each square millimeter of horizontal surface.

2. With droplets 10 microns in diameter, these would be approximately 1,000 droplets for each square millimeter of horizontal surface.

3. With droplets 1 micron in diameter, there would be 1,000,000 droplets for each square millimeter of horizontal surface.

Even where the leaf surface of covering vegetation may have greatly increased the total "acreage" beyond that of the "horizontal surface", this enormously multiplied number of droplets together with their slower settling through constantly eddying air, should help to assure adequate coverage.

These data on dispersion are given special significance by our new high power insecticides, such as DDT. Why, then, should we look further? Why not use DDT in the finest aerosol fogs, and consider our pest control problems solved?

Why not? Because some of the physical factors which govern the behavior of individual particles in a disperse system, such as the air suspended droplets of an aerosol oil fog, present very definitely limiting conditions.

SOME LIMITING FACTORS

It is convenient to distinguish three kinds of aerosols:

1. DUSTS OR MISTS, in which the particles are larger than 10 microns in diameter. Such particles settle in still air with increasing velocity. *They do not diffuse,* or tend, as does a gas, to escape through crevices in an enclosure.

2. CLOUDS OR FOGS, in which the particles range in diameter from 10 microns to 0.1 micron. Such particles settle in still air at a constant velocity which varies with the diameter of the particle. *They, also, do not diffuse.*

3. SMOKES, the particles of which range from 0.1 micron to 0.01 micron. Such particles are small enough to be pushed about by the impact of surrounding air molecules (which are in constant motion at average velocities of about a quarter of a mile per second), and show the resulting "Brownian movement". They settle very, very slowly, or not at all in still air; and, varying with particle diameter, or with mass and associated Brownian activity, *they diffuse more or less rapidly;* though never as rapidly as do the molecules of a gas.

Any particle suspended in a gas (as in air) is subject to two sets of forces:

1. It is pulled downward by *gravity.*
2. Its downward fall is *resisted* by the viscosity of the gas.

In general, for particles larger than 10 microns diameter, *Gravity* is greater than *Resistance* at all velocities, and the particle settles with constantly increasing velocity.

For particles smaller than 10 microns diameter, *Resistance* increases as the velocity of the particle increases until *Resistance* becomes equal to *Gravity,* and the particle then continues to fall at a constant velocity.

RATE OF FALL IN STILL AIR FOR DROPLETS OF DIFFERENT DIAMETERS

Diameter of Particle	Rate of Fall per Second (About)	Time to Fall One Foot (About)	Time to Fall from 10 Foot Ceiling to Floor (About)
100 microns	30 centimeters or 12 inches	1 foot in 1 second	10 ft. in 10 seconds
10 microns	3 millimeters or 1/8 inch	1 foot in 1⅔ min.	10 ft. in 16⅔ min.
1 micron	30 microns or 1/800 inch	1 foot in 2¾ hours	10 ft. in 27½ hours
0.1 micron	0.3 microns or 1/80,000 inch	1 foot in 11½ days	10 ft. in 115 days

From this table it is clear that different pest control problems may be most effectually served only by aerosol fogs of appropriate mass-average and range of droplet diameters.

For indoor pest control operations, aerosol fogs of very small droplet diameter that will remain for many hours suspended in the air, will eddy with convection currents most effectually into spots that are difficult to reach.

For outdoor use, spray or fogs of larger droplet diameter must be used to avoid wasteful transportation by winds beyond the limits of set objectives, and to assure effectual deposit of the insecticide.

Neither standard mechanical spray outfits delivering mists of 100 micron average droplet diameters or smaller, nor thermal aerosol fog generators, drive the mist or fog any great distance from the nozzle. Indoors, convection currents and associated eddy currents will rapidly carry a fine aerosol fog throughoutout all parts of an enclosed space. Outdoors, however, aerosol fogs must depend for much of their unique effectiveness on horizontal transportation by wind. Here, again, we encounter a very signficant scale of values.

A four mile per hour wind is little more than a gentle breeze; but let us see how far droplets of different diameters starting at an elevation of four feet will be carried on a four mile wind before they settle to the ground (four feet being an average height for the nozzle of a fog generator).

These mushrooming figures which so rapidly assume proportions that sound astronomical, serve merely to illustrate the basic complexity of the problems associated with the investigation of aerosol fogs, and with their adaptation to practical use.

Actually, four mile winds never blow continuously for thousands, or even scores of miles; and air, even indoors, is rarely so still that the droplets of sprays or fogs may settle evenly downward.

On the contrary, both indoors and outdoors, convection currents, eddy currents and the like, complicate the pattern tremendously; and introduce special problems that must be taken seriously into account in any discussion of particle size.

Not the least of these special problems are those associated with the deposition of wind-borne aerosol fog droplets on objects in their path.

Here Dr. Glasgow paused in his comments on particle size to open the discussion (see page 27).
After a few comments at the conclusion of the discussion (see page 29), he resumed:

The wind-borne droplets of an insecticide aerosol fog may be considered as minute, death dealing projectiles moving substantially in parallel horizontal lines; for with a highly potent insecticide like DDT, even extremely small droplets may be made each to carry a killing dose of the poison.

A wind blowing toward a stationary object tends to hold against the side of the object which faces the wind a cushion of dead air that divides the approaching wind current and diverts it to right and left. A similar relation is set up by an object, such as an insect, moving in still air.

Wind borne aerosol fog droplets, theoretically, may move in horizontal straight lines in open spaces; but they tend to follow the resulting curved flow lines, as the passing wind is deflected to the right or left of obstacles encountered in its course.

For the same quantity of material dis-

DROPLET DIAMETER, RATE OF FALL IN STILL AIR, AND DISTANCE CARRIED

Droplet Diameter	Rate of Fall per Second (About)	Time to Fall 1 Foot (About)	Distance Carried While Settling 1 Foot (About)
100 microns	1 foot	1 foot in 1 second	23–7/15 feet
10 microns	⅛ inch	1 foot in 1⅔ min.	2346–2/3 feet
1 micron	30 microns	1 foot in 2¾ hours	44 miles
0.1 micron	0.3 micron	1 foot in 11½ days	4404 miles

persed as an aerosol fog, when used indoors, or when used for flying insects out of doors, droplets of small diameter will give a closer and more effective barrage; just as the same weight of metal in the form of machine gun fire will stop advancing enemy troops more effectually than it would in the form of large calibre solid shot.

On the other hand, to continue the simile, for wind-borne large scale coverage of vegetation and the like, where we must break through a barrier cushion of still air, we are obliged, artillery like, to choose aerosol fogs of larger droplet diameter in order that the greater momentum of the heavier particles, by holding a straighter course, may more effectually smash through the obstructing cushion of dead air, and actually deposit the insecticide where needed.

In general, a broader object will be shielded by a correspondingly deeper cushion of dead air; with the result that in a wind borne aerosol fog a hair, or the leg or antenna of a mosquito for example, may receive a greater number of direct hits than would a lead pencil.

Furthermore, more droplets will be deposited near the margin, than at the center of an object; and, by contrast with the shielding cushion of dead air facing the approaching wind, there will be a zone of turbulence immediately behind the object with an even greater deposit of droplets on its back.

THE QUESTION OF RESIDUAL DEPOSIT

It is true that with some insoluble and nonvolatile insecticides such as DDT, lead arsenate, cryolite, and the like, there are places where their use for prolonged or "residual" effect is important. Such use usually means a relatively heavy deposit in places where the insect to be controlled will be likely at some later time to come into effectual contact with the poison. The residual effectiveness of the arsenicals and other stomach poisons has long been known and used. DDT has special interest for such use, because of its prolonged effectiveness under suitable conditions as a residual contact insecticide.

For example, an adequately prolonged, residual, indoor mosquito control operation would require a deposit of something like 200 milligrams of actual DDT per square foot of ceiling and wall surface. This would be at the rate of about 17½ pounds of DDT per acre.

One gram, or roughly 30 four-millimeter drops of a 20% solution would be required to carry 200 milligrams of DDT. Applied as a mechanical spray of 100 micron droplets, there would be about 20 droplets for each square millimetre of the surface to be covered. Of a 5% solution, there would be about 80 droplets for each square millimetre.

As a driving spray, the relatively heavy, 100 micron diameter droplets would easily smash through the barrier cushion of still air, and come to rest as a deposit on the wall surface behind.

It would obviously be very difficult, if not wholly impracticable to build up such a heavy deposit by means of an aerosol fog; although surprisingly persistent residual effects have been observed where aerosol fogs of larger droplet diameter have been used with more highly concentrated formulas.

DISCUSSION

DR. GLASGOW: Before continuing further, I think we should take time out to give an opportunity for discussion.

But, first, we are fortunate to have with us this morning a man who has been doing some particularly outstanding research work, not only on the practical use of aerosol fogs in the field, but notably also, on fundamental studies of some of the special problems just mentioned. I refer especially to the wind tunnel studies of aerosol fogs that have been carried on at Beltsville, Maryland, by Mr. R. K. Latta, of the United States Bureau of Entomology and Plant Quarantine.

I know we shall all be glad to hear Mr. Latta tell us something of the work that he has been doing; and, later, I am sure that he will be glad to answer any questions about his work that we may care to ask him.

MR. LATTA: (From stenographer's report of the meeting.) We have been involved in this study of particle size at the Beltsville Laboratory for about a year and a half or two years, and have gathered together all of the information that we could from various sources. We have also carried on experiments in the field and in the laboratory, the latter including studies of the deposition of aerosol droplets in a wind tunnel on objects of different kinds. Insects as well as other miscellaneous objects were exposed to aerosol fogs passing through the wind tunnel at various velocities. Variously coated glass slides were exposed in order to study how the droplets are deposited.

One suggestion I might have is on the preparation of slides. We have used the zinc stearate coating on slides, but we found that we have quite a few failures. We tried to follow the problem of coating slides to get a coating material that would be easier to use. We have two that we use now. One is to take one of the spreading agents that you can buy on the market—NNO. Wash the slide, dip it in a one-tenth per cent solution in alcohol. Let dry, and polish. With that slide we have very few failures. We found that we can make slides in this manner in quantity much faster than with zinc stearate. We use this method in preference to one of the silicones produced by the General Electric Company, called "Dry Film."

For study, the slide bearing a deposit of droplets is placed under a microscope and projected on a screen that is cross hatched. Two persons sitting in front of the screen can then count and measure large numbers of particles very rapidly.

Mr. Sammis: In view of the fact that mosquito control operators are mainly interested in getting a coating on the vegetation, is there any difference between the coating on specially prepared slides, and that on various types of vegetation? Are the values comparable?

Mr. Latta: No. At Beltsville right now we are making special studies of the deposition of aerosols. It is dependent upon the shape of the object upon which the deposition is made, and upon the size of the particle. And not only on the shape of the object, but also upon the size. The way it runs, the smaller and more curved the object, the better the deposition of aerosol particles. Grass, or pine needles, or any foliage of that character, will collect a good quantity of the aerosol as it goes by.

With a drifting aerosol cloud, for each type of object that is interposed in its path, there is a calculable amount of deposit.

The smaller the particle, the more tendency it has to drift around the object. As you increase the size of the particles, a larger and larger number will strike the same type of object in their path. When they strike, we assume that deposition has occurred.

This is also associated with the speed of the particles.

All of these factors taken together will give you some idea of your deposition pattern.

There are two causes of deposition. One is the drifting particle striking an object in its path. The other is the settling factor as the particles fall closer and closer to ground. In the first case, whether the particle in horizontal movement strikes an object in its path, is related to the size of the particle, and the speed at which it is moving. In the second case, the particles may settle on a flat surface.

Mr. Nelson: Are there any measurements on the electrostatic charge on the leaf surface, in relation to the particle itself?

Mr. Latta: We do not believe that electrostatic charges enter into the picture. That is the story that is accepted on dust particles, but we haven't seen any evidence on liquid particles. We have been studying the action of aerosols in a wind tunnel. We can duplicate our tests all the time, and pay no attention to these electrostatic conditions. If they were a factor, they would certainly upset the work that we are doing.

Mr. Dorer: (Did not get question.) (Probably, How much residual deposit does the aerosol leave? Editor's note.)

Mr. Latta: You are asking a question we know no answer to yet. We are trying to learn all about aerosols that we can. We know that aerosol is the best method of striking insects. We know that the deposition on insects from small particles is much greater than it is on foliage. We are studying the factor of deposition because it is very important in many ways, and we are finding that there is a considerable amount of deposition, and that it is a pattern which is concerned with two definite facts. You can contact the insect with the insecticide and in that the finer the particle the better chance you have.

There is some effect from the deposit that is left. It is there. We don't know how much, but we are trying to find out what sort of a deposition you get from an aerosol. You have a gradation of deposition as you go down in particle size. Eventually, particle size is so small that the deposition is practically nil; but there will be some fraction of a per cent. So far, we have considered that an aerosol is our principal means of killing insects by direct contact; and we are finding that there is not enough residual deposition left to be effective.

Question: Have you tested the pyrethrum insecticides in aerosol?

Mr. Latta: No, we have not reached that point yet. Our work has been restricted to fundamental studies of aerosols. There is no reason why pyrethrum aerosol cannot be made. The heat that is developed by the thermal generators looks very high when you read the thermometer; but at the same time contact is almost instantaneous, and to break down the insecticide takes time. In our early work, the first test we made used an army screening smoke generator and added DDT to the fog oil. Temperatures ran from 900° to 1000° F. We tried pyrethrum in that generator, but our results were not too good. With the newer type generators we have now, pyrethrum and nicotine have been used.

Question: In using a solution, are we to assume that each droplet contains a percentage of the element?

Mr. Latta: We haven't determined so far, but are assuming that is so. In the way aerosols are formed now your solution never changes its form. The oil is not evaporated; it is only broken up. There is one qualification. If you use Xylene in the formula, this evaporates and does not re-enter the particles.

Dr. Glasgow: Thank you, Mr. Latta.. You have brought out several very important points that merit special comment. (For resumption of Dr. Glosgow's comments, see continuation from manuscript submitted, beginning on page 27.)

In the afternoon session, Mr. Latta gave an extremely interesting and informative account of the fundamental studies of aerosol fogs and of particle size that are now being carried on at Beltsville; he did not leave a manuscript, and unfortunately, through a misunderstanding, a stenographic report of his talk was not made.

President Ruth: Dr. Glasgow has asked Dr. Collins to describe and demonstrate the technique employed by Dr. Collins and him to photograph and measure aerosol fog particles.

With a compound microscope and a Leica camera, Dr. Collins demonstrated the simple method of making simultaneously a photomicrograph of the aerosol fog droplets as collected on an oleophobic coated slide, together with the superposed image of a micrometer scale for their measurement.

The remarks accompanying the demonstration are printed below under the title *Technique Employed in the Study and Measurement of Aerosol Fog Droplets.* The general "set-up", and a few of the specimen photomicrographs which were shown as lantern slides, are reproduced.

TECHNIQUE EMPLOYED IN THE STUDY AND MEASUREMENT OF AEROSOL FOG DROPLETS

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For an accurate check on the performance of an aerosol fog generator with different formulas, and for a clear understanding of the possibilities and limitations of fogs composed of droplets of different average diameters, it was necessary to find some practical method not only of measuring but also of recording the droplet diameters.

For simplicity of manipulation, and for ease and speed with which permanent records may be made in the field during field experiments or actual control operations, the photographic method of studying particle size and other particle characteristics which was developed by the New York State Science Service has proven extremely useful.

Photomicrographs can be made literally as fast as the microscope can be focused and refocused on different areas of a slide. Thus a large series of permanent photographic records of droplet patterns, together with a superposed scale for the accurate measurement of the droplet diameters, may be made of significant, some-