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光電霧滴計數器

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空氣中浮懸微體（aerosols）及天然（或人造）霧之霧滴的大小與濃度（指單位容積內之數量）的準確測量，是應用物理學與氣象學上的一大難題。所有業經採用的測量方法，均有缺點頗多，結果且不一致，尤以對水霧微滴（water fog droplet）的大小分佈與濃度的測量，困難最多(1)。Gucker 等(2)曾設計的光電計數器，每分鐘可記錄直徑在 0.6 微米以上的固體或膠體微粒至一千個，然並不能適用於水霧滴及濃度較大的任何空中浮懸微體。本文所敘述的光電霧滴計數器，係利用一多極光電管（photomultiplier）記錄每一水霧微滴經過一微小光柱的散射光。其主要構造及測量原理如次：

（1）使空氣中水霧滴以等速通過一點光源經透鏡裝置後而聚集成的微小光柱；（2）由一與光柱及霧滴進行路徑成垂直方向的多極光電管記錄每一單獨霧滴經過此光柱時的散射光；（3）光電管的輸出經過幾級放大及濾波器後并由：（a）標記器（scaler）計數，（b）陰極射線示波器及記錄攝影機記錄每一霧滴經過光柱時所引起之脈搏的大小。因此項光電管的響應至速，故本計數器的計數極限，實決定所用標記器的計數極限。因所用者是 Berkeley 型 1000B，故最高計數率爲每分鐘可量霧滴三十萬個，故能適用於一般的濃度的任何空氣中浮懸微體。綜合近年來在水霧滴大小分佈方面的各種測量的結果，似乎水霧（天然及人造）霧滴的半徑均在一微米以上(4)，本霧滴計數器，當可記錄之而無遺漏。其效能當可由增高光電管之訊號噪音比，或採用兩個光電管的符合記數裝置而提高。

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(1) Y. T. Wei, Ph.D. Thesis, Physics, Dept. University of California, Los Angeles (1950), Chap. II.

(2) F. T. Gucker Jr. and C. T. O'Konski, *J. of Colloid. Sc.* **4** (1949), 541.

(4). 參看，例如：I. Langmuir, "Super Cooled Water Droplets in Rising Current of Cooled Saturated Air" G.E. Co., Schenectady, (1944) 及 (1).

本計數器發展尚未臻完善，其最大困難厥是無適當簡單理論預計霧滴散射光强度與霧滴大小的準確關係。然由初步實驗結果可以推斷，如施以適當改善，本計數器必能成爲節時而較可靠的水霧滴（及一般空中浮懸微體）之濃度與大小分佈的指示器。

本文敍述的各要點次序如下：

（1）現階段的本霧滴計數器的構造與測量方法。

（2）示波器脈搏大小與霧滴大小的關係。

（3）初步測量的結果。

（4）本計數器的可能改善之點。

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A PHOTO-ELECTRONIC FOG COUNTER*

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Abstract

A photo-electronic fog counter has been developed on the principle of counting flashes of light scattered from individual fog droplets with a photomultiplier. Since a photomultiplier appears to act very rapidly and reponse in a time of the order of 10^{-8} sec. is possible, the maximum counting rate is limited only by the scaler which is associated with the counter. If a Berkeley Scaler (Model 1000B) is used, this counter is capable of counting fog droplets at a rate of 300,000/min. with very small error and the chance of coincidence countings is therefore small. This counter will prove useful for even very dense fogs or any other kind of aerosols. The optical theory of scattering which may lead to the determination of particle size from size of electric pulse has been introduced.

Preliminary experiments show the applicability of this counter for droplet size measurement. There seems to be of no doubt that this counter could register the smallest droplets that occur in natural fogs (i.e., of the order of $r \simeq 1$ micron) and a better sensitivity can be achieved by reducing stray-light noise level and improving signal to noise ratio. Possibilities of further improvements of the present instrument both as a fog counter and as a droplet size indicator have been discussed.

Introduction

Several different methods have been developed for counting small aerosols. The Guyton counter[1] was designed by counting the electric pulses imparted to a metal collector (usually a thin copper wire) by particles forced through a fine jet at a high velocity. It has been assumed that the height of these pulses is proportional to the electrostatic charge that a particle can hold. These pulses are then amplified through a three-stage high frequency amplifier and rectified by the grid of the fourth stage. However there has been much uncertainty as to how the charge is produced (even by Guyton himself) and to detect impulses of a few microvolts (which correspond to particles of $r=1$ micron) through a series of amplifiers without being masked by the thermal noise arising from these multiple-stage amplifications remains

*This paper is based on a part of the author's work performed at the Physics Department, University of California, Los Angeles, U.S.A., completed in May 1951.

1. A. C. Guyton, *Journ. Ind. Hyg. Toxicol.* **28** (1946), 133.

a serious problem. Methods of tedious visual countings reported by May[2] and Sonkin[3] would fail completely if they were used for counting fog droplets. The ultramicroscopic counting method[4, 5] can be made useful only if some other technique of stopping the motion of the aerosols (such as by strong stroboscopic light of very short duration) can be developed instead of a mechanical method. Gucker[6, 7, 8] and his colaborators have counted aerosols photo-electronically. As reported, their counter could count aerosols of diameter 0.6 micron and up at a maximum rate of 1000/min. This device is not applicable for counting liquid drops or concentrated aerosols. It seems that a photo-electronic device utilizing a similiar principle as in a scintillation detector developed recently by nuclear physicists remains a unique method for counting small aerosols including fog droplets. Owing to the lack of standard methods of measuring fog concentration and particle size such a fog counter has long been very much desired if any investigation is to be made in connection with a foggy atmosphere.

The Fog Counter at its Present Stage

The present photo-electronic counter to be described has an appearance shown in Fig. 1 C. It consists of essentially a concentrated light source, a

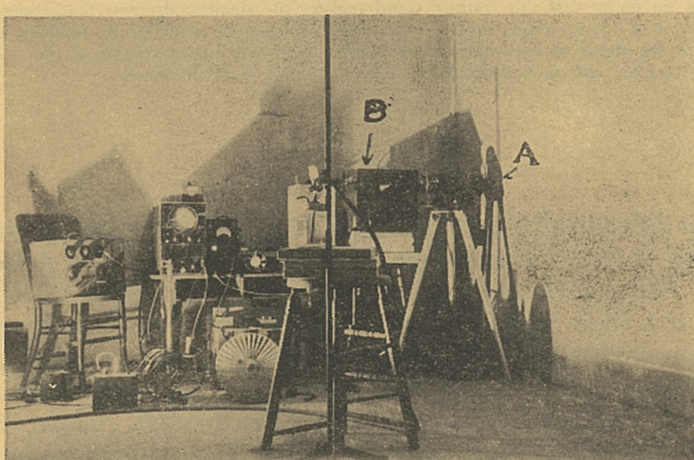

Fig. 1 A

2. R. K. May, *J. Sci. Instr.* **22** (1945), 187.
3. L. S. Sonkin, *Journ. Ind. Hyg. Toxicol.* **28** (1946), 269.
4. G. Nonhebel, J. Colvin, H. S. Patterson and R. Whytlaw-Gray, *Proc. Roy. Soc.*, A, **116** (1926), 540.
5. H. S. Patterson and R. Whytlaw-Gray, *Proc. Roy. Soc.*, A, **124** (1929), 502.
6. F. T. Gucker Jr. and C. T. O'Konski, *Chem. Rev.* **44** (1949), 373.
7. P. T. Gucker Jr. and C. T. O'Konski, *J. of Colloid. Sc.* **4** (1949), 541.
8. F. T. Gucker Jr., C. T. O'Konski, H. B. Pickard and J. N. Pitts, *J. Am. Chem. Soc.* **69** (1947), 2422.

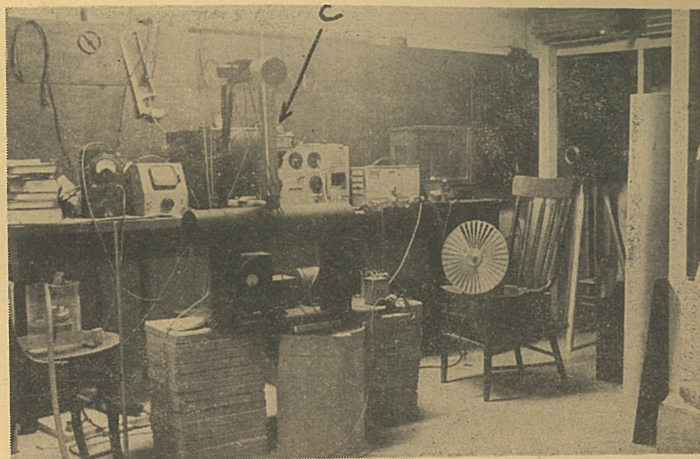

Fig. 1 B

Fig. 1 A, B. The Evolution of the Photo-electronic Counter. Fig. 1 A shows a preliminary set-up (right-hand corner) while measurement of panticle size and concentration were being made in artificial fog produced in the Reverberation Room with a Hg-arc (A) and a separate receiver (B). This set-up has later been developed into one unit shown in the center of Fig. 1 B (C).

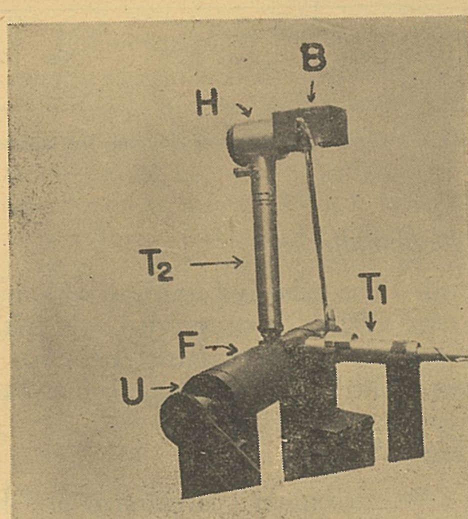

Fig. 1 C. The Photo-electronic Fog Counter at its Present Stage.

photomultiplier and a flow tube for fog droplets. The electrical pulse from the photomulitiplier has been amplified two stage before it is fed into the scaler. The electrical circuit in connection with the counter is described in Fig. 2.

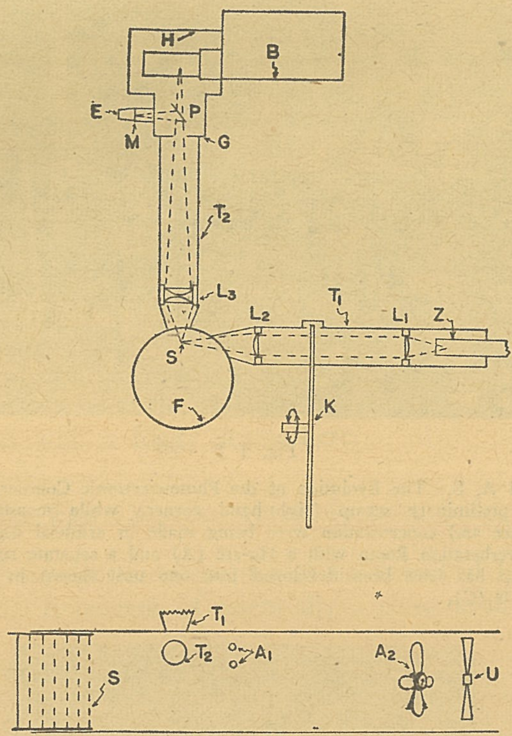

Fig. 2. Construction of photo-electronic fog counter

(A) *The Photomultiplier*

RCA IP28 is used. The tube is furnished with quartz walls and has maximum response near 3400Å. It is operated at a voltage of less than 100 v. per stage. It has been found to be fairly stable for an operation which lasts less than one hour. The background noise is found to be $\simeq$1.2 mv.

(B) *The Light Source*

Western Union 2-W. zirconium concentrated arc[9] has a maximum intrinsic brightness of 100 c.p./mm^2 which is almost the equivalent of a carbon arc. The heating effect produced by such a low wattage arc to its surroundings is small. The diameter of the concentrated and nearly uniformly illuminated arc is 0.003 cm. The optical spectra transmitted from the window is from 0.3 to 5 microns, only spectra of the shorter range will actuate IP28. A filter can be conveniently used to cut off spectra of longer wave-length.

9. W. D. Buckingham and C. R. Deibert *J. Opt. Soc. Am.* **36** (1946), 245.

(C) *The Optical System*

It has been shown by Rayleigh[10], Mie[11] and Blumer[12] that the intensity of the scattered light from a small particle at a right angle is only one-half that in forward direction, and even less than that for smaller particles. Thus the stray-light (or the light arising from molecular scattering) is greatly reduced by such a right angle system. The present fog counter (Fig. 2) is constructed with the path of the light beam (tube T_1) subtended at a right angle with the receiver (tube T_2). Both T_1 and T_2 are metal tubes of dia. 2″ (darkened inside) and with truncated cones set on a 5″ flow tube T. The horizontal tube T_1 consists of a zirconium concentrated arc Z at one end. The light is first rendered into parallel by the 1½″ f=4 cm. quartz lens L_1. The light chopper K furnishes a means of reducing the D.C. light to A.C. of 1000 c.p.s., and thus facilitates the focussing and adjustment of the optical system. Quartz lens L_2 condenses the incident parallel light into focus again. By proper adjustment of L_1 and L_2 it is always possible to focus the arc in the tube F and along the optical axis of the receiving tube T_2 (point S). The flow tube F (about 2 ft. in length) is furnished with a fan unit U at one end to draw the foggy air from the other end. The maximum flow speed we can get from a still fog is 8 ft/sec. The rate of flow can be varied by changing the speed of the motor and conveniently measured by a thermo-anemometer A_1 (Wilson Prod. Co.) together with a moving-vane type anemometer A_2. The screen unit S_1 consisting of six layers of stainless steel screens can be conveniently inserted in the flow tube F for total liquid amount measurement. This also serves a means for checking the collection efficiency of such a screen collector*. The scattered light from the fog droplets will be received by the phototube through the quartz lens system L_3 (f=2 in.). Since the focussed light beam is only a fraction of a centimeter beyond the focal point of this lens, a magnified image is formed, however the portion of the scattered light that will actuate the phototube can be controlled by the variable diaphragm G. Since a quartz plate P is set at a 45° angle to the scattered light, a real image of the same size will be formed on the translucent scale M, therefore a magnified virtual image can be observed through the eyepiece E. All lenses are furnished with screw adjustments for position. H is the tube housing. The voltage divider and preamplifier are built in the box B. The inside walls of the whole system are painted black so that the straylight is reduced to a minimum.

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10. Lord Rayleigh, *Phil. Mag.* **5** (1899), 375, etc.
11. G. Mie, *Ann. d. Physik,* Leipzig, **25** (1908), 128.
12. H. Blumer, *Zeit. f. Physik* **38** (1926), 920.

*A screen collector by copying Houghton's (Ref. 13) has been constructed previously for measuring total liquid water amount in artificial fogs produced in the reverberation room of the Acoustic Laboratory of UCLA. Repetitious measurements conducted by the author showed that the collection efficiency varies among other things with the particle size of the fog.

13. H. G. Houghton and W. H. Radford, *Pap. Phys. Ocean. Meter.* Mass. Inst. of Technology and Woods Hole Ocean. Inst., **6** (1938), No. 4.

(D) *The Preamplifier*

The circuit is shown in Fig. 3. It has a flat response from 100 up to 100,000 c.p.s. The photomultiplier background noise output from the pre-

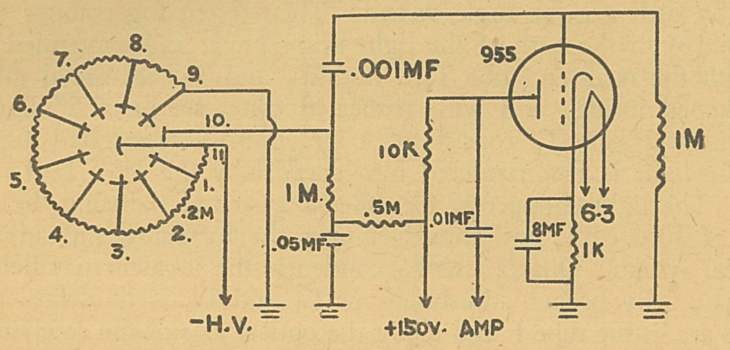

Fig. 3. The preamplifier

amplifier is about 0.012 v. or 12 mv. The contribution of stray-light noise can be made negligible by adjusting the diaphragm.

(E) *The Amplifier*

A battery operated wide-band amplifier is preferred. The Ballatine Model 220 decade amplifier has been found to be fairly quiet and gives good response up to 100,000 c.p.s. If a Ballantine volt-meter Model 300 is used either in connection with or in place of the amplifier, a 60 c.p.s. band rejection filter together with a wave filter[7] must be used besides shielding all leads. The amplifier was operated most of the time at a gain of 20 db.

(F) *The Scaler*

The Berkely Scaler Model 1000B has been used. The mechanical register is capable of operating at 5 counts/sec, a rate of 5000/sec. or 300,000/min. can be attained with very small error if all three decimal counting units are used.

The scaler will count a negative pulse of ¼v. or higher. The pulses that are counted have standardized height, while those below ¼v. have a pulse height proportional to the original.

(G) *Counting Rate Meter*

A high speed logarithmic level recorder (Sound Apparatus Co.) can conveniently be used as a counting rate meter after careful calibration.

Relation between Pulse-Size and Particle Size

The well-known Rayleigh's law of scattering predicts that the intensity of light scattered from small particles is directly proportional to the sixth power of the radius and inversely proportional to the fourth power of the optical wave-length of the incident light. This applies only to particles of smaller order of magnitude than the wave length of the incident light. Mie[11] has made extensive study on the problem of scattering of light by minute particles of suspension of finite conductivity in dielectric medium. By assuming the clouding of spherical particles optically infinitely thin (i.e., the influence of the particles on secondary radiation was disregarded) he characterized the electromagnetic field inside and outside the sphere by the dielectric constant, the conductivity, and the magnetic permeability. The integrals of Maxwell's equations are the sum of products of spherical and cylindrical functions. The solution of the problem is effected by dividing the integrals into a series of partial solutions which give the amplitudes of the secondary waves which go out from the particle in all directions and which are super-imposed on the incident plane waves. By applying limiting conditions to scattered spherical surface, Mie obtained certain expressions for the field component inside and outside the sphere and finally obtained formulas for intensity scattered in any direction from the incident wave. Diving the scattered light into two linear polarized components at right angle, we have,

$$\left.\begin{aligned} I_1 &= \frac{\lambda^2}{4\pi^2\tau^2}\, i_1 \\ I_2 &= \frac{\lambda^2}{4\pi^2\tau^2}\, i_2 \end{aligned}\right\} \tag{1}$$

where

$$i_1 = \left| \sum_{\nu=1}^{\infty} \left\{ \frac{a_\nu}{\nu(\nu+1)}\, \pi_\nu + \frac{p_\nu}{\nu(\nu+1)} \left[v\,\pi_\nu - (1 - v^2)\, \pi'_\nu \right] \right\} \right|^2$$

$$i_2 = \left| \sum_{\nu=1}^{\infty} \left\{ \frac{a_\nu}{\nu(\nu+1)} \left[v\pi_\nu - (1 - v^2)\, \pi'_\nu \right] + \frac{p_\nu}{\nu(\nu+1)}\, \pi_\nu \right\} \right|^2$$

I_1 has the electric field perpendicular to plane of vision

I_2 has the electric field oscillating in plane of vision

π_ν: ν-th spherical functions

$\pi_\nu{}'$: its derivative

a_ν, p_ν: complex coefficients, which represent the ν-th electrical and magnetic partial waves

By Equ. (1), it is theoretically possible to calculate the intensity of the scattered light from spheres of any desired size with any desired physical constant. For small spheres it is always true that $|a_{\nu+1}| < |a_\nu|, |p_{\nu+1}| < |p_\nu|$ in such a way that the series converges rapidly, i.e., the radiation reflected from a small sphere is composed mainly of a finite number of partial waves. But the number of partial waves increases if the sphere becomes large. Very small particle always radiates only first electrical oscillation, which is thus identical with Rayleigh's law of scattering. There have been both theoretical and experimental investigations of the problem by many authors such as Debye[14], Jobst[15], Blumer[2], Stratton and Houghton[16], LaMer[18], Sinclair[19], Brillouin[20], and Houghton and Chalker[21], etc. Numerical investigations made thus far apply only to very special cases and the solutions are approximate. Blumer[12] has shown that as the diameter of the particle exceeds 4λ of the primary light, the cylindrical functions converge too slowly. To work out a complete numerical solution corresponding to these cases is therefore a very tedious task although not impossible.

Stratton and Houghton[16] have confined Mie's theory to visible range for small uniform fog droplets. By assuming zero conductivity and four partial fields, two within and two without the sphere and by applying the approximate method of Jobst[15] and Debye[14], these authors have written the intensity of transmitted light in the form for plane incident waves,

$$I_t = I_0 \, e^{-2\pi N r^2 \tau K_s} \tag{2}$$

(where N: no. of droplets/cc, τ: distance traversed in the foggy medium in centimeters) and evaluated K_s—which is a series expansion consisting of Bessel and Hankel functions—corresponding to different values of α $(=2\pi r/\lambda)$. Houghton and Chalker[21] have ameliorated these calculations. (Fig. 4). As far as optical scattering in fogs in visible and ultraviolet rays is concerned, the square law is true approximately. Since little information has been found in both artificial and natural fogs for droplets below $r \simeq 1$ micron, and the maximum frequency occurs from[22] $r = 1$ to $10\,\mu$, the

14. P. Debye, *Phys. Zeit.* **9** (1908), 775.
15. G. Jobst, *Ann. d. Phys.* **4** (1925), 76, 863.
16. J. A. Stratton and H. G. Houghton, *Phys. Rev.* **38** (1931), 159.
17. A. Sommerfeld, *Partial Differential Equations in Physics* (Acad. Press, N.Y., 1949).
18. V. K. LaMer, *J. Colloid. Sc.* **1** (1946), 79.
19. D. Sinclair, *J. Opt. Soc. Am.* **37** (1947), 475.
20. D. Brillouin, *J. Appl. Phys.* **20** (1949), 110.
21. H. G. Houghton and W. R. Chalker, *J. Opt. Soc. Am.* **39** (1949), 955.
22. Y. T. Wei, Ph. D. Thesis, Phys. Dept., Univ. of Calif., Los Angeles, U.S.A., 1950.

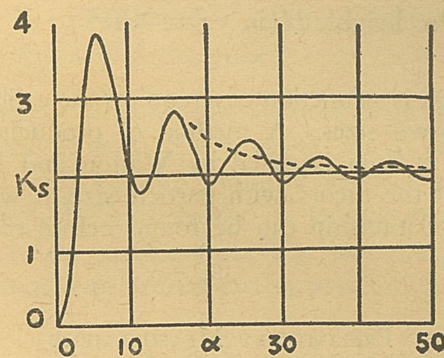

Fig. 4. *Ks* vs *α*. Dotted Lines: extended by Van de Hulst (Disertation, Utrecht, Holland) using Jobst's asymptotic solution.
(After Houghton and Chalker)

scattering belongs to the shadow case (Fig. 4). From the computations of Houghton and Chalker:

α $\left(\frac{2\pi r}{\lambda}\right)$	K_s scattering area coeff.	α $\left(\frac{2\pi r}{\lambda}\right)$	K_s scattering area coeff.
0.5	0.00676	13	2.012
0.6	0.0138	19	2.218
1.0	0.0938	19.75	1.976
1.2	0.171	20	2.18
10.0	2.5152	21	1.834
12.0	1.67	24	2.438

In our case, it is reasonable to assume that the scattered light which actuates the phototube is of $\lambda \simeq$ 4000Å, the value of α therefore varies from 15.8 for $r=1$ micron to 158 for $r=10$ microns. From Fig. 4 we see that the deviation of K_s from 2 is less than 10% in the $r=1$ micron case. As shown by Brillouin,[20] $K_s \to 1$ as $\alpha \to 160$, a limit beyond which the scattering is strictly geometrical optics. Thus this theory applies only to a droplet up to $r=10$ microns, which is however not the upper limit of droplet size of a natural fog. In order to make this theory to be applicable to droplet of all sizes, several optical filters are probably necessary. Further let us assume tentatively the simple quadratic relation:

$$\text{The pulse height. } H(\text{in volts}) \simeq Kr^2 \tag{3}$$

To determine K which is a function of r requires the calibration of the counter with droplets of known sizes. A method of producing a mist of known and uniform sizes has been reported by Walton and Prewitt[23]. Owing to the varying nature of the theory with particle size, it would be preferable if a certain empirical relationship can be found before conducting a measurement.

Preliminary Measurement

An arrangement has been made according to Fig. 5. An electron tube voltmeter E. V. is used for testing signal to noise ratio. Adjust lens L_1 and position of the concentrated arc so that a parallel light is formed (which can be detected by inserting a small translucent scale in the slot K to see that a uniformly illuminated area of $1\frac{1}{2}''$ in diameter is formed). This is also to insure that the illumination from the light source has been utilized to its maximum extent.

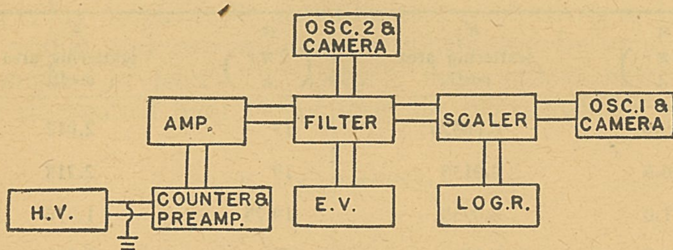

Fig. 5. Block Diagram of Electronic Circuit

Adjust L_2 so that the light is brought to focus right below the center of the cone of the receiver. By adjusting L_3 until a sharp image from a small glass rod in the direct focused beam forms on the translucent scale M. By adjusting the variable diaphragm so that only a small portion* of the scattered light will actuate the phototube. This effective illuminated area can be calculated from the size of the image observed in scale M and diameter of the light cone from T_1 to S, which can be measured at its best by inserting a microscope in a hole opposite to the tube T_1. Since only droplets passing through the part of illuminated volume formed by the two cones (approximately cylindrical in shape) will be counted, it is desirable to know

23. W. H. Walton and Prewitt, *Proc. Phys. Soc.*, London, **62** (1949), 341.

*The variable diaphragm has a minimum radius of 1/16″. Both visual and photographic observations failed to diclose any interference fringes.

its exact dimensions in order to calculate the absolute droplet number per unit volume and the duration of the pulses.

Both cigarette smoke streams and artificial fogs from a water sprayer have been injected into the flow tube while the speed of flow is of the range 4–8 ft/sec. The gain control of the amplifier has been adjusted so that while no particles pass through the light stream, the voltage as read from the vacuum tube voltmeter is far below ¼ of a volt. The following is one of the typical data of such a preliminary measurement for artificial fog.

(1) Background noise: 120 mv. (output for amplifier)

(2) Background noise and stray-light noise (arc lamp on): 135 mv.

(3) No. of counts from scaler/sec. corresponding to (2) (in every ten seconds): 60; 100; 30; 42; 32; 45; 52; 46; 36; 42;
Ave. 4.85/sec.

(4) No. of counts from scaler/sec. when fog droplets flow at a speed of 8 ft/sec. (in every ten seconds):
6498; 6320; 6750; 6628; 6321: 6428; 6058; 6700; 6100;
Ave. 642.1/sec.

(5) Diameter of the focussed concentrated arc: 0.1 cm.

(6) Diameter of the illuminated volume that will actuate the phototube: 0.0125 cm.

(7) Flow speed: 8 ft./sec.

From the above data we can calculate the no. of droplets/cc of the fog in question:

$$N = \frac{642{\cdot}1}{8 \times 30{\cdot}48 \times 1{\cdot}25 \times 10^{-3}} \simeq 2{\cdot}1 \times 10^3/\text{cc}.$$

The chance of coincidence count is very small since we can see easily that the longest duration of an electric pulse is:

$$\frac{\cdot 0125}{8 \times 30{\cdot}48} \simeq 5 \times 10^{-5} \text{ sec. or } 50 \ \mu\text{-sec}.$$

Both still film camera and continuous film camera have been used to record the pulses shown on the oscilloscope screens. Results are shown in Fig. 6. Owing to the very short duration of the pulses, oscilloscopes with higher accelerating voltage tubes are required to achieve better results.

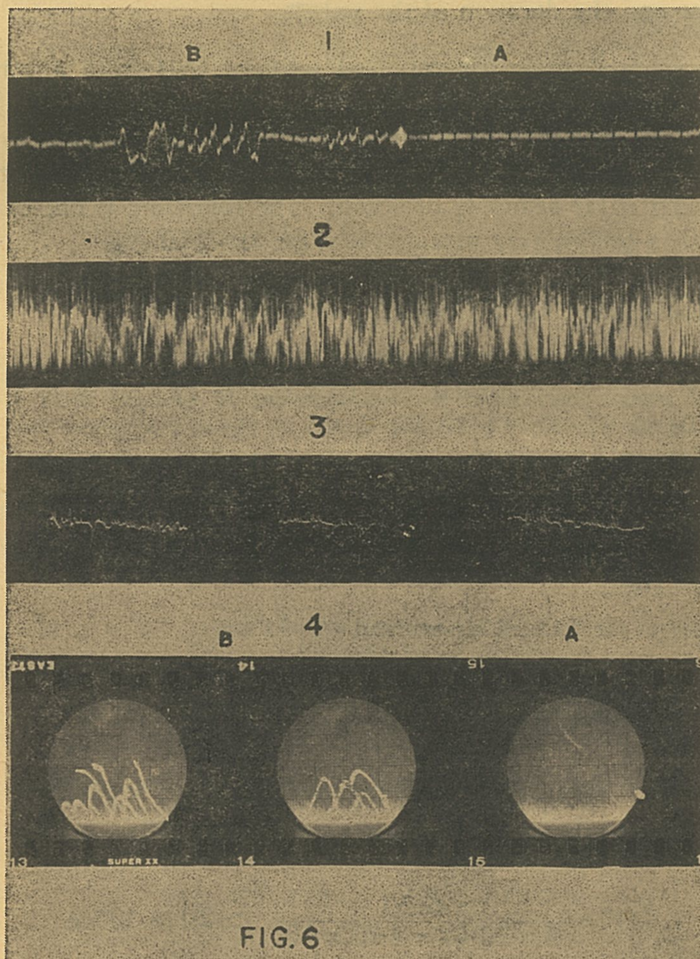

Fig. 6. Oscillographic Records for Artificial Fog and Cigarette Smoke.

(1) Moving film record from Osc. 2 in one sec.
A: Background noise; B: Cigarette Smoke at 8 ft./sec.

(2) Moving film record from Osc. 2 in one sec. for artificial fog at 8 ft./sec. while the camera is in sychronization with the scaler. Both (1) and (2) show that better resolution for single pulses can only be obtained with higher film speed.

(3) Still film record from Osc. 2 for background noise. Exposure time 1/30 sec.

(4) Still film record from Osc. 1 for artificial fog. Exposure time 1/30 sec. The original appearance of this kind of record is like (A), the pulses are hardly visible. (B) is obtained by retouching the negative only to show the pulse shape.

FUTURE DEVELOPMENT OF THE PHOTO-ELECTRONIC FOG COUNTER

The photo-electronic counter at its present stage is by no means very satisfactory. Improvements can be made regarding the following:

(1) To measure the pulse size distribution: In spite of the fact that a multiple channel discriminator circuit is available,[24] a single channel discriminator would suit our present purpose. If a scaler with no built-in discriminator were used, a high impedence attenuator could serve the purpose.

(2) For accurate determination of droplet size, we should not rely too much on any theory. Calibration of the counter with droplets of known sizes would give more reliable results.

(3) To reduce the background noise of the counter, two methods can be used: (a) by cooling of phototube with dry ice or a refragerating system[25], (b) by using of two photomultipliers and with an optical system so arranged that both tubes are sensitive only to exactly the same illuminated volume and with their outputs in coincidence[26]. Noise pulses are of random nature, but scattered light signals will be time-coincident. This technique was originally applied to scintillation counters.

(4) At very low flow speed, the flow speed can be measured most accurately with a set-up similar to a Rayleigh disc.

(5) A rectangular slit should replace the variable diaphragm with circular aperture. This would give an effective illuminated volume in which all particles traverse in equal intervals.

(6) For measuring particles with a wide distribution of sizes, the voltage output should be made to be a linear function of the logarithm of the scattered light intensity. This can be attained by connecting the last dynode of the phototube to an insulated amplifier-tube control grid.[27]

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24. See, for instance, E. Gatti, *Nuovo Cim.* **7** (1950), 655.
25. R. W. Engstron, *J. Opt. Soc. Am.* **37** (1947), 420.
26. G. A. Morton and K. W. Robinson, *Nucleonics* **4** (1949), 25.
27. M. H. Sweet, *Electronics* **19** (1946), 105.