NEPHELOMETRIC DETERMINATION OF MINIMUM BACK SCATTER TO LIGHT FROM FIELD DUST

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PREFACE

That field dust limits night field operations, I have observed in many localities, from Oklahoma to the Philippines. First suggestion for solution of this problem by light scatter diagrams was from the study of optics in physical meteorology. The experiment of this study is an attempt at applying light scatter techniques to finding methods of minimizing glare from field dust.

Light scatter studies combine several scientific fields. Much of the theory was developed by theoretical physicists who later brought quantum mechanics to prominence as A. Einstein. Applied experiments on atmospheric scatter have been made by technicians and practical engineers. Physical meteorologists have contributed to light scatter information by studies from curiosity about atmospheric phenomena and attempts at measuring visibility.

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TABLE OF CONTENTS

LIST OF TABLES

Table | Page

LIST OF FIGURES

Figure | Page

Figure	Page

I. INTRODUCTION

Adequate artificial illumination is needed for the operator of field equipment during night field operations to insure effective control and maintain safety. The source of illumination has developed from working by moonlight with lanterns to present systems of tractor lights with specially designed illumination distribution patterns.

The need for better illumination is intensified by new practices and technological developments. One new practice that may increase operator comfort is night operation to avoid heat and insects. Another is the use of larger and more expensive machines. This causes machine utilization to be more important than the time of day which the operator would prefer to use the equipment.

Many agricultural operations have an optimum time during which the field work should be done. This optimum time period may be of a very short duration. Field operations may be carried on at night to insure completion within the recommended time.

A consideration of weather conditions and other factors can lead one to recommend completing a field operation as soon as possible. When adequate artificial illumination is available, night provides additional time for accomplishing these operations. Considering indications that now exist can lead one to recommend crop practices or treating methods be accomplished at night because of some special plant physiology.

Night operation of field equipment at increased speeds necessitates more extensive and higher levels of illumination. More complex equipment which requires greater operator attention increases the need for proper illumination at night. The need for more accurate control of improved mechanical, electrical or electronic systems increases the need for better illumination.

Field dust clouds accompany moving field machinery any time the soil surface is dry. These dust clouds are caused from contact of the ground by the equipment. In many situations, especially when the equipment is travelling downwind nearly parallel to wind direction, this dust cloud surrounds the operator of field equipment. Night operation of field equipment during earth-moving and tillage operations often creates a field dust cloud of high concentration. The high mounting of lights on field equipment causes sufficient glare from the dust cloud to obscure the operator's view of the ground ahead. Under these conditions, night operation is often prohibitive and certainly unsafe.

This study is an attempt to investigate a method of minimizing glare from field dust so an operator of field equipment can adequately see during night operation.

II. REVIEW OF THE LITERATURE

A. Light Scatter

Scattering of light is caused by a wave of light hitting a solid particle. It energizes the molecules of that particle to radiate the light again from the surface. A beam of light which strikes a small particle energizes the charges of the molecules on the whole particle causing it to reradiate the light waves in all directions (1). This is primary scattering of light. Further scatter of previously scattered light is multiple scattering.

Any illumination of a beam of light is caused by light scattering from the solid particles in that beam. The amount of light scattered in all directions plus any light absorbed by large opaque particles plus the remaining light of the beam not scattered by the particles equals the total amount of light originally in the beam.

Light scatter at a certain angle from a light beam can be measured as a constant light intensity for a mixture of homogeneous scattering particles. Light scattered from a particle toward the forward direction of the light beam is called forward scatter. Scatter toward the light beam source is called back scatter. Experimental results in literature are presented in forward scatter angles or back scatter angles (2). Forward scatter angles are measured at the scattering particles from the forward direction of the light source to the place the scattering is being measured.

Conversely, back scatter angles are measured from the light source. The back scatter angle is the supplement of the forward scatter angle.

The scatter of light by particles is a field of investigation considered a pure science until recently. In instances of its appearance in applied problems, the extensive investigation of light scatter by astronomers and theoretical physicists has rarely been used.

Curiosity about atmospheric phenomena prompted its earliest interest. Leonardo Da Vinci (circa 1500) first realized that the blue of the sky was caused by light scattering from particles in the air (3). Rayleigh (4), in 1871, first realized that haze, which obscurs visibility, was caused by small particle scattering. He developed the theory of light scatter for particles about the same size as the wavelength of light (5). From Rayleigh's development, it became recognized that light scatter could be predicted theoretically. Application of the Rayleigh theory was made to small particles but was considered by investigators as not applicable to particles larger than the wavelength (6). Particles above six-tenths microns are larger than the wavelength of visible light (7).

Limitations of application led to formulation of Rayleigh-Gans scattering which considered the refractive index, a measure of the reflection of the surface, of the scattering particles (8). Finally, Mie (9) developed a derivation valid for all size particles, including those much larger than the wavelength of light interms of Maxwell's electromagnetic equations (10,11). The Mie theory, with modifications, can be used to predict angular scattering of large dust particles.

The Mie theory with theoretical developments shows that a dimensionless constant is the ratio of $2\pi r/\omega$, where r is the radius of the scattering particle and ω is the wavelength of light. The scattering intensity of light at forward scatter angle θ is:

$$I = \frac{G^2}{\omega^2 r^2} I_o \left[D(\theta, \phi) \right]^2$$

I = Scattered light intensity at angle θ.

I_o = Light intensity of the source.

G = Area integral, $\iint dx\, dy$ of the geometric area of the cross-section of the particle.

$$D(\theta, \phi) = \frac{1}{G} \iint e^{-ik\,(x \cos \phi + y \sin \phi) \sin \theta}\, dx\, dy$$

r = Radius of the scattering particle.

ω = Wavelength of light.

k = Propagation constant.

ϕ = Angle from the x-axis, for polar coordinate interpretation.

θ = Angle from the z-axis.

x and y = Length and width of the particle.

Recently, light scattering theory for useful applications has been generalized, for example, by Van De Hulst (8). Previously developed theories are being tested and applied by calculation of scatter in specific directions for differing values of the ratio of particle size to wavelength, mentioned above (3, 12). Calculation of scatter involves Bessel functions and spherical harmonics (1). Solution of these equations has necessitated use of the largest digital computers (13).

Gumprecht and Sliepcevich (13) have made the only calculation of angular scatter for particles as large as field dust scatterers, but they apply only to an angle of zero to seven degrees forward scattering. Sinclair and La Mer (14) tried to calculate angular scatter values for smoke particles. They found that for particles above two-tenths micron in diameter, the equations produced multiple values of angular scatter, from which no most likely value could be picked.

All calculations of angular scatter have been for spherical particles. Application of calculations for spherical particles to other shapes has long been assumed to be impossible (6). Investigators now consider that an aerosol of any shape particles which are randomly oriented in suspension, will scatter light the same as spheres (8).

A limitation of the Mie equations is that they do not consider the absorption of light. Small transparent particles absorb no light. Absorption of light is assumed to occur in large dust particles. Prediction of angular scatter including absorption is considered impossible from present theoretical equations.

Many suggestions were found for using polarized light to reduce light scattering. Theoretical explanation of how it would reduce scattering is lacking except that Rosenberg and Mikhailin (15) explain characteristics of light, affected by polarization, which vary angular scattering.

B. Nephelometers

Angular scatter measurement can be made with an instrument called a nephelometer (1). Parts of a nephelometer are (A) a chamber to hold the aerosol, (B) a beam of light to shine through the aerosol and (C) a method of measuring the illumination intensity at an angle from the light beam. Most nephelometers have provisions for measuring light at many angles (16). In comparison, a photometer is an instrument which measures illumination intensity, which may be used to measure light at zero or ninety degrees forward scatter angle, being fixed in position. Some definitions of a nephelometer include a statement that the angular scatter intensity is compared to a standard known illumination intensity or angular scatter intensity from a standard suspension of which the scatter characteristics are known (17, 18).

Little consideration has been given dust as a light scatterer. The first references to dust were as explanations of unusual results to scattering of small particles of chemical compounds (19). Plotnikow found more scattering than anticipated from chemical compounds. He judged this was due to clustering together of the molecules (20). Krishnan (21) attacked this hypothesis, sensing that the larger particles causing the unusual scattering were dust particles. For this he assumed that dust particles scattered large amounts of light and that the scattering noted was the same as that expected from dust.

Some nephelometers have used, as the aerosol from which the scattering was measured, a sample of the actual particle cloud under study. Sinclair and La Mer (14) generated smoke used in their nephelometer. Simon, Kron, Watson and Raymond (22) studied blast furnace gas in a line carrying this gas to the blast furnace to measure light scatter from the dust in this gas. Waldram (23) used air from the upper atmosphere to measure the scatter of dust in it by carrying the nephelometer in an airplane and balloon.

Field dust, the aerosol of this problem, would be difficult to obtain in constant concentration in a field condition. A sample of it cannot be allowed to rest because the large particles, assumed to contribute most scattering, will settle out of the air. Possibilities for making artificial dust clouds were contained in Green and Lane's review (24) of methods of generating dust clouds for pneumoconiosis research. Also methods were found from tests of dust filters for engines and dust sampling instruments. The primary problem is keeping the dust, in storage, from aggregating because of attraction forces when in sizes of a few microns.

One method of reducing the aggregating effect of the particles was to never permit small size particles to be at rest. This was achieved by a continuous scraping of a dust clod to obtain the proper particle sizes. In another system, the dust is ground in a tumble mill which operated only when the motor was energized by a photocell relay. This kept the optical density of the dust cloud at a constant level. Another method was the use of a long narrow tube of dust which is slowly raised. The dust was drawn from the tube through an orifice into the dust cloud chamber.

Light sources for nephelometers have mostly consisted of tungsten filaments. Historically, at least one application of the sun's rays as light source has been reported made by Ananthakrishman (20). Tungsten filament light sources are almost all reported of over two hundred watt sizes (3). These were necessitated because of cutout of most of the light by pin-hole beam arrangements. The use of such an extremely narrow beam lessened the optical problems (12). Also a narrow beam was considered best for forward scattering at very low angles which has been considered by experimenters as the most stable type of scattering (2).

Within the limits of the tungsten filament light source, many divisions still exist from the use of filters, either on light source or photometer. The commercial nephelometers, the Phoenix and Aminco (3) use blue and green filters because of their high light transmittance. Oriented particles direct certain frequencies to one scatter angle which is used to identify the particles. Randomly arranged particles scatter white light in all directions (25). Filters can be used on randomly oriented particles to obtain differing angular scattering diagrams. Possibilities exist for light sources of narrower frequency range than normal color filters. One type are special artificial sources like sodium light used to test fog by Luckish and Holladay (16). Another is the dual monochromator produced from two diffraction gratings, as devised by Land (26).

Measurement of illumination intensity of the scattered light is the last fundamental part of a nephelometer. Equipment to measure this intensity was the limiting feature of many scatter experiments until development of the phototube. Some of the early experimenters used their eyes for intensity judgement. Waldram (27) used a photometric wedge for the light measurement. It was a calibrated intensity attenuating device used to produce a light intensity comparable by the eye to the scatter intensity.

The most sensitive method of measuring light intensity is a phototube having a cathode which emits electrons when recieving light. The anode collects the electrons by an external voltage source. This source is usually direct current but may be alternating, using only the positive part of the current cycle to the anode for the electron flow. The electron flow of very small currents can then be measured across a resistence from which voltage drop can be detected. The multiplier phototube has several stages through which the cathode electrons can be amplified by dynode stages many hundred thousand times.

The main characteristic of the phototube is the wavelengths to which it is sensitive. The infra-red (22) or the ultra-violet (16) ranges can be used for phototube sources as well as the visual range frequencies. Because of the interest in several fields of visual range frequencies, several phototubes have been built which are sensitive only to the visual ranges in approximately the same proportion intensity levels for each color frequency as is the average human eye.

Gumprecht and Sliebcevich (13) describe a method of determining what small range of angles is sensed at one angular measurement position. Accuracy in absolute light intensity measurements is established by comparison of scatter intensity to a standard known intensity of light. This feature was built in some nephelometers as by Pyaskovskays-Fesenkova (28) for sunlight and Gunker and Peterson (17) to a standard gas.

So few nephelometers have been built that the main achievement in most has been finding characteristics of the mechanism and some scatter indications. Only in application to chemical compounds in solution have nephelometers become refined enough to allow commercial manufacture (3).

Results of scattering experiments are few. Review of results will cover only those using a suspension in air as the aerosol. Most of the researchers inferred from the few angles they measured, a smoothed curve of scatter for all angles. The earliest results were from open atmosphere experiments. Open atmosphere experiments suffer from variables, particularly varying consistency of the dust cloud.

First results from Rocard (27) and Hulburt (25) on atmospheric haze produced angular scatter curves. These curves show a maximum scatter intensity at forward scatter angles and minimum scatter intensity at one hundred twenty degrees back scatter. Bulrich and Siedentopy (16) reported experimental results for haze of a maximum of scatter intensity at both the forward scatter and back scatter limits of their nephelometer. In their results, a minimum scatter intensity occured at one hundred twenty degrees back scatter angle. Billmeyer (2) reported a scatter diagram of haze which has maximum scatter intensity for forward scatter. It has another maximum scatter intensity, not as high value as forward scatter angles, at back scatter angles. Also the scatter normal to the light beam is a minimum of scatter intensity.

The most extensive measurements of haze scatter diagrams have been reported by Waldram (27). He measured more angles accurately with more replications than the other experimenters. He found much variance in diagrams because of varying concentration of dust in the air. For surface haze, near industrial smoke, he found maximum forward scattering and minimum values ranging from one hundred twenty to ninety degrees forward scatter. Back scattering reached a peak, about one-third the maximum of forward scattering. His measurements were made only from forty two to one hundred sixty degrees forward scatter.

The only other nephelometer reported in literature measuring angular light scatter on a polydisperse, many particle size, aerosol was the OWL by Sinclair and La Mer (14). The aerosol was a heterogenous smoke. The object was to measure size and size distribution. The light sources were frequencies of low wavelengths. Smoke entering the chamber had to be kept dispersed to have proper optical density and avoid coagulation, at density of not over one hundred thousand particles per cubic centimeter. Later work of Sinclair and La Mer (29) was aimed at the production of a monodisperse, one size particle, aerosol for which they hoped to determine particle size from measurements of light transmission, color, intensity and polarization.

C. Polydisperse Aerosol Scattering

Light scattering measurements on particles with wide range of sizes results in less accurate measurements and less reliable results for determining characteristics of particles than when uniform one size particles are used (12). This is particularly true for differing types of particles (30). Light scattering of many sizes of particles is a composite of the scattering of individual particles of each size (31). The variability of this scattering from size will determine how consistent polydisperse scattering will be.

Large particles scatter proportionally much more than small particles. Thus, heterogeneous polydisperse dust clouds will produce scattering characteristic of particles larger than their geometrical mean diameter. A more uniform size cloud, at least one of smaller particles, will scatter more characteristically as the average effective size of scatterers (31). On basis of size distribution, there are many more small dust particles than large (31). The particles under a few microns in size may account for the majority by number, but by weight, they will represent a small proportion.

Extinction of light by absorption in solid particles is much less clearly understood than is angular scattering (32). Until recently, particles large and opaque enough to absorb light were kept out of consideration and out of experiments. As comparison, scattering from transparent spheres is considered much more reliable theoretically (33). Experiments on dust in blast furnace gas tend to show that extinction varied directly with width of the dust cloud (19). With cloud size constant, concentration was found to vary directly with extinction. Angular scatter tests indicated that absorption occurs when particles are as large or larger than the wavelength (33).

Experiments on atmospheric haze have been attempted to determine the characteristic size of the scattering particle. This is one approach to measuring sizes of these particles. A summary of Moller's work stated that the average scatter of haze was as spheres of one micron radius. Billmeyer (2) characterized scatter from haze as less than one micron in radius.

The main conclusion of Moller's study was that the larger size dust particles do not result in an influence on the distribution of scattered radiation. This statement, if true, would negate the hypothesis of this problem. The supporting data and actual article could not be found.

D. Field Dust

Dust clouds are an aerosol of solid materials suspended in a gaseous medium (24). The solid materials are small size earthy particles (7) of many possible sources while the gaseous medium in the open atmosphere is a homogeneous mixture of all the molecules of the atmosphere.

Solid particles which are not hydrometeors, all forms of atmospheric moisture particles, or gases found in the open atmosphere can be considered dust except that dense smoke concentrations (7) are identified as more uniform smaller particles identifiable from a source. Recent definition of smoke (33) classifies it as any aerosol of particles, solid or liquid, less than one micron. For most applications, the particles considered dust are larger than the gas molecules.

Haze is a meteorological term for visibility restriction caused by light scattering of dust suspended in the atmosphere. Haze cannot be discerned from hydrometeors, especially distant fog, since it is usually difficult to distinguish between the type of particles. Thus haze contains dust and is a dust cloud of low concentration and small particle size.

The differing physical characteristics of the dust cloud are most attributed to the solid materials which are recognized for study as particle sources, shapes (31) and concentration (32). Green and Lane (24) explain that most dust consists of particles of irregular shape either in the form of single units or as aggregates. Sometimes well-defined crystalline forms may be identified, but even so, the study of dusts is complicated by the shape factor and is less amenable to firm analysis than where particles are spherical. Even some solid particles initially spherical may experience aggregation which again introduces the shape factor.

The ASHAE Air-Borne Dust Survey (31) classified solid particles found in air consisting generally of mineral fractions of fine size distribution, carbonaceous fractions of coarse size distribution and fibers. Shapes of these dust particles are (A) spherical, consisting of smokes, pollen and fly ash; (B) irregular cubical mineral cinder; (C) flakes of minerals and epidermis; (D) fibrous, lint and plant fiber and (E) condensation floccs, carbon, smokes and fumes.

Dusts tend to be very heterogeneous systems of poor stability and contain more large particles than mists and smokes. The particles in many dusts tend to attract each other aggregating with considerable force.

Since the dust in dust clouds includes such a wide range of sizes and materials, being that which is not uniform enough to slassify as another particulate cloud, characterizing it is difficult. Large particles and aggregates of them can be separated by screens through which particles the size of the screen air space and smaller will pass when shaken across the face of the screen. This method, while reliable for larger particle sizes, produces many mechanical difficulties in sizing the smaller ones. Screens have been manufactured for sizes greater than forty microns (7). Dust particles about fifty microns are large enough to be seen with the naked eye (35).

The particulate cloud, characteristic of moving field machinery aerosol environment, will be called field dust. A review of literature reveals very little information about field dust, mostly consisting of conjecture and certain assumptions when have been made to applied studies in an environment of it.

It is generally assumed that field dust ranges in size up to one hundred microns (36). A lack of hypotheses on field dust cause even a definition of it to be difficult. Size distribution range is shown in Table I for three different field dusts.

TABLE I

DUST SIZE DISTRIBUTION ON WEIGHT BASIS

Particle Size In Microns	Arizona Dust % by Weight	California Dust % by Weight	Desert Dust % by Weight
0-5	13.1	16.7	39
6-23	15.4	35.9	34
24-43	54.2	42.3	18
Above 43	17.3	5.1	9

The Arizona size distribution type is considered standard by the Society of Automotive Engineers for tests of air cleaners (37). The third column in Table I, by Overholt (38), is for a desert environment, not average field dust. Desert dust is modified by blowing through the air and by collisions with other particles which helps reduce the particle size. Shape of the particles vary from spheres to jagged edges. Field dust appears characteristically sharp-edged and hard. The abrasion of dust is determined by the shape and amount of quartz present (39).

Field dust is ninety to ninety eight percent mineral matter, the remainder being organic matter (39). The ASHAE Air-Borne Dust Survey (31) of normal atmospheric dust in outdoor air showed a bimodal cumulative size distribution curve composed of mineral fraction for one mode and carbonaceous fraction for the other. Distribution in the summer showed only one mode explained as diminishment of the carbonaceous part. For a typical particle, field dust could be characterized from these indications as mineral matter.

Concentration of dust particles is one of the least studied aspects because it is difficult to determine. Since particle sizes and shapes are not uniform, dust concentration determination has only been attempted in commercial gas (40). The solid materials of the air are not seen by the naked eye until they cause sufficient light scattering to become visible. Even the highest dust concentrations, contain many more gas molecules than dust particles, even though the cloud is opaque and absorbs light.

Most dust particles in the air are found in aggregates (31). These solid particles tend to clump (7) and become tightly bound together requiring severe mechanical dispersion to break these bonds (31). This is because of the attraction due to the Van der Walls forces of interatomic forces between ions which decreases with the seventh power of the distance which separates them (7). Moisture has a significant effect in the sense that an absorbed layer of polar molecules may give rise to large forces of adhesion. Density of a dust cloud is little different from density of the air (24). Electrical charges have little effect on the dust cloud.

Dust cloud analysis needs an adequate explanation of why the solid materials stay in suspension. Drinker and Hatch (7) consider the mass of small dust particles so small that they achieve equilibrum by being moved around in air by the gas molecules. This oscillating motion is known as the Brownonian motion which has been described by Einstein as:

$$A = \frac{\sqrt{RT}\ t}{N\ 3\ \pi/d}$$

A = Amplitude of motion in given time t.

R = Gas constant.

N = Avogadro's number.

T = Absolute temperature.

d = Particle diameter in microns.

Identifiable levels of movement of the dust in air became first recognized as the Brownonian movement on the molecular scale. The next level are fluctuations of the same order in turbulent mixing of moving air in transport as identified by Bagnold (41) which puts dust into the air. Final level is the convective updrafts and pressure systems in the atmosphere which carry the dust high into the air and far in distance. For field dust, the only difference is that the last movement, would be a smaller scale effect.

Particles fall out of the air with a steady velocity in direct proportion to the square of the diameter according to Stokes Law (21). In calm air, from gravity, Stokes Law produces a fallout of:

$$D = \frac{k}{\sqrt{t}}$$

D = Diameter of largest particle in light beam after elapsed time t from start of settling.

$$k = \frac{\sqrt{18\ h\ \omega}}{\sqrt{g_L\ (p_1 - p_2)}}$$

h = Settling height.

ω = Viscosity of settling medium.

g_L = Local acceleration of gravity.

$p_1 - p_2$ = Differential in density of dispersed particles and surrounding matter.

Another interpretation of Stokes Law is:

$$V = \frac{2}{9}\ \frac{g_L\ (D_p - D_a)\ r^2}{\omega}$$

g_L = Local acceleration of gravity.

D_p = Density of the particles.

D_a = Density of surrounding air.

r = Radius of particles.

ω = Viscosity of settling medium.

For particles less than one micron in diameter, a revision is necessary to include Millikan's term, multiplying for velicity by (42):

$$1 + \frac{L}{r}\ (A + B\ e^{-c\frac{r}{L}})$$

L = Mean free path of the molecules

A, B and C = constants.

E. Field Dust Operations

Location of the light to minimize back scatter has been studied by the author (43) in an open atmosphere field test. The advantage of study in the field was that the field dust cloud is not always uniform from ground to above operator eye level as is a thick layer of fog.

The dust produced by wheels and soil disturbing portions of the implement, raises to the rear of the tractor where the operator rides. In still air this dust will remain above the place from which it was thrown, being suspended in air. In a light or moderate wind, the dust is propelled forward in the direction of the wind. Even a light wind will cause the dust in the air to move faster than the tractor causing the dust to move past the implement to the tractor continuing to the front of the tractor, into the path of the headlights. The ground is then obscured because of the reflected light. Since the dust travels with the wind, in one direction of vehicle travel downwind, the dust problem is most severe.

Solution to the location problem has been achieved by mounting the light to travel through as small amount of dust as possible. The best solution found for these requirements is the mounting of two lights as far forward and as low as possible.(43).

This arrangement of lighting units was used for field operations during extremely dusty conditions. The conventionally mounted headlights were retained to compare with the new dust lights.

The dust lights worked satisfactorily and were tested over an extensive period of field operation. These lights were observed from darkness to the next sunrise when tillage operations were being performed on very dusty land. The pattern, though adequate when dusty, did not cover quite as large an area when the dense field dust cloud was present. On occasion, the use of conventionally mounted tractor lights in addition to the low forward dust lights would obscure the ground ahead due to the glare they produced.

III. STATEMENT OF SPECIFIC OBJECTIVES

A. The Experiment

The objective of this experiment was to find angular back scatter characteristics of a dust cloud representative of the light scatter of a field dust cloud. A nephelometer was to be used for angular back scatter measurements of different light frequencies and dust particles. A feature of this nephelometer was to be angle measurements which could be made every degree.

B. Limitations of the Study

In this study, the use of equipment to measure relative values comparable only to other relative values rather than absolute values of angular scatter intensity was justified since the primary interest was in determining angles at which minimum back scatter may be observed to occur.

Limitations were: (A) Use of recording instruments, needed for accurate discontinuity determination, which were not available for this experiment. (B) Use of a tungsten filament light source because of its standardized application in headlight units. (C) Obtaining small particle range groups. (D) Control over humidity of dust cloud environment. This may vary particle aggregation when obtaining the particle cloud and scattering properties of hygroscopic dust which has an affinity for moisture. (E) Constant voltage source for amplification of photometer light. The only available source was line power system with varying voltage.

IV. EQUIPMENT FOR EXPERIMENT ON PROBLEM

A. Characterizing the Field Dust Cloud

Size distribution is the main feature of characterizing the field dust cloud. Scattering data and theory indicates that the largest particles will back scatter and absorb the most light. Thus, it is important to limit the largest size in the field dust cloud to that of the largest field dust particle. Indications from literature show this should be one hundred microns.

In order that the experimental results be applicable to the field condition, the dust cloud to be tested should have the same light scattering characteristics as the field dust cloud. The degree of multiple scattering, scattering of scattered light, if any, should be the same in both cases. However, it cannot be determined for either.

Also the type particles used in the experiment should approximate those found in the field. The most predominant type, mineral fractions, would be the best representation of field dust. Mineral fractions with little humus matter and plant fiber are the consistency of normal field soils. Pulverized field soil will be used as the dust cloud particles.

To obtain this, a soil was obtained of typical mineral composition containing a large percentage of particles of sizes that and below the size of field dust. This was Reinach Silt Loam. It was analyzed in a thesis by Rosenberg (44) as containing a large majority of particles in size distribution between twenty three and fifty microns, containing particle sizes down to a few microns, his lower limit of measurement.

The soil was ground with a Braun Pulverizer, Type UA. It was kept in closed metal cans. When not in use, they were placed in a warm oven. It was found that the smallest pulverization of the soil sample produced most particles in the size range under one hundred microns. Most of the experiment will use this pulverized soil for dust cloud.

Three size distributions were obtained by sieving with a Cenco-Meinzer Sieve Shaker, Number 18480. Sieves were all U. S. Standard Sieve Series, ASTM Specifications. They ranged in size from: largest, 105 micron opening, Number 140; middle, 74 micron opening, Number 200 and smallest, opening 53 microns, Number 270.

Small samples of soil were used for each sieving for two and one-half minutes after which each sieve was cleaned with compressed air. These sieves are impractical for a large quantity of material. Cutoff of the small size ranges is poorly attained by trying to sieve a large quantity of material by this system. About all that can be said about the resulting size distribution is that the largest size should be that of the screen it passed through.

B. The Nephelometer

A preliminary test was performed on a plastic cylinder container of air and dust which was occasionally agitated to keep the dust in suspension. Results were that the surface of the plastic cylinder became so quickly coated with a layer of dust particles, that the cloud inside could not be seen. Opening the container showed the particles swirling inside around the heat source of the light beam even though it had a heat filter. This method was judged unsatisfactory. The obvious indication seemed to be to disperse the dust into open atmospheric air by some type of sieve. The problem in sieving dust was to maintain a cloud of constant concentration.

A constant dispersion was obtained from rotating six large diameter wires over the top of a wire screen. These six wires, one-sixteenth inch in diameter, were mounted radially around the circular area and were joined in the center. The wires were driven by a rotating metal cylinder from above. The radial mounting might have been considered to have the effect of sweeping more dust out of the center than the edges of the circle, but this was offset by the slower linear motion of the dispersing surface toward the center. An agitator was included to keep the dust from bridging over the inside of the cylinder and to feed it at a uniform rate to the dispersing surface below. The agitator and wire discharge screen were held stationary.

A two inch diameter was used for the circular dust cloud, which by preliminary test, was indicated to be the lower limit of availability of a constant consistency cloud by the sifting method. For low scatter angle measurement, a small diameter cloud with small diameter illumination and sensing beams would allow a lower angle limit if close mechanical spacing were possible. To vary the concentration of the dust cloud, a variable speed electric mixer motor was used to drive the sifter. Tests indicated that its slowest speed, one hundred sixty revolutions per minute, produced a dense cloud which fast began to decrease in concentration with lowering of the dust level. The dust concentration increased after starting the sifter, becoming constant in three seconds. From this constant rate, concentration began to decrease after eight seconds.

Figure 1 shows the assembled nephelometer used in the experiment. Figure 2 shows the schematic diagram of it. Since the photometer was expected to be larger than the light source apparatus, it was held stationary while the light source was rotated through calibrated angles from the photometer.

The light source location was arranged to be varied by means of a tray which would rotate on an axis concentric with the center of the dust cloud. This axis reference was obtained from the top of the drive motor of the sifter. A rotating arm from this axis shaft would provide a constant radial reference for the light source. To keep the phototube and light source in proper alignment, a retractable target of two wires in the shape of a cross were used in the center of the dust cloud.

A phototube was used to measure the low intensity scattered light. The tube was an RCA 931-A photomultiplier tube used in the commercial nephelometers. It had the S-4 spectral response designated by illumination engineers to approximate human eye characteristics. It has almost no response into the infra-red range and the ultraviolet is not apt to be present in a tungsten filament source with lenses. In multiplier application of dynodes from the cathode, it is capable of eight to eleven hundred-thousand times amplification when the dynodes are operating at one hundred volts per stage.

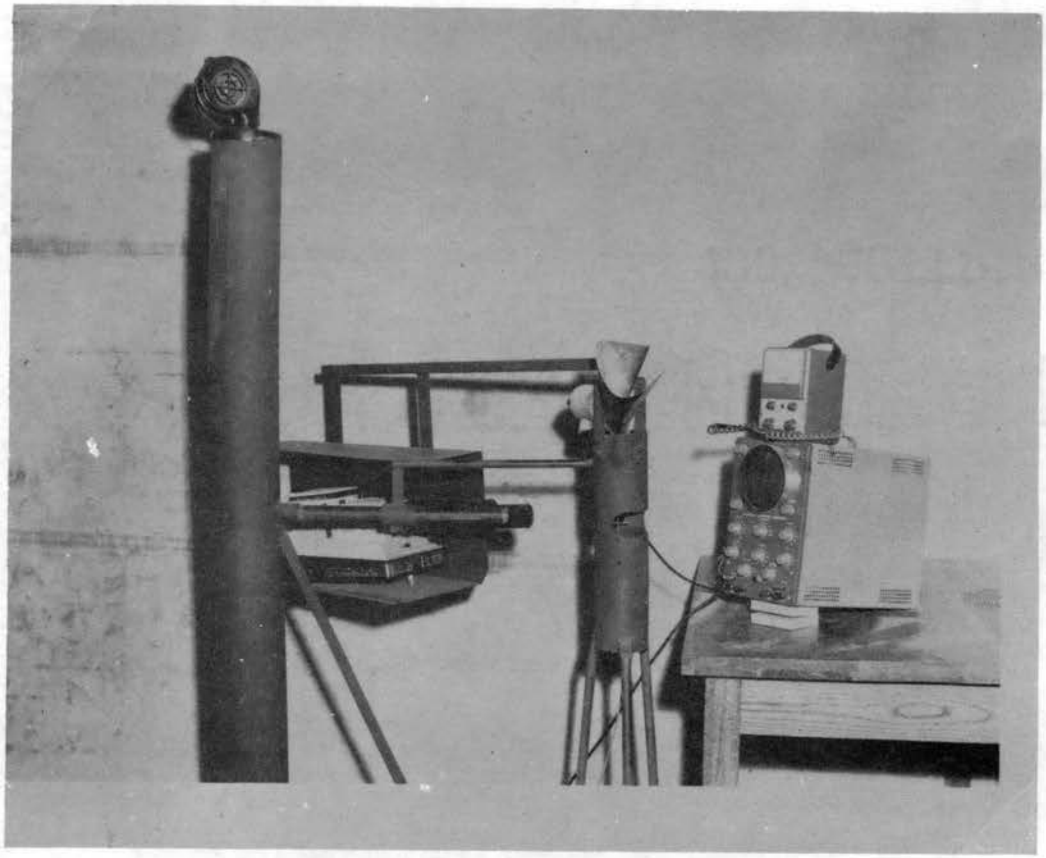


FIGURE 1. NEPHELOMETER OF THE EXPERIMENT

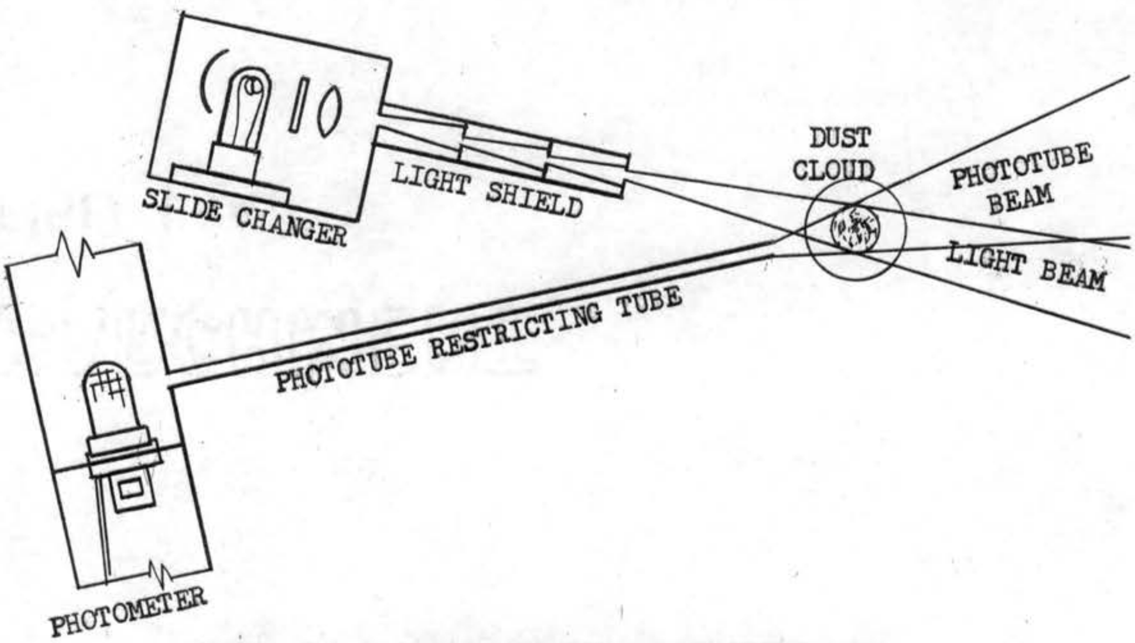


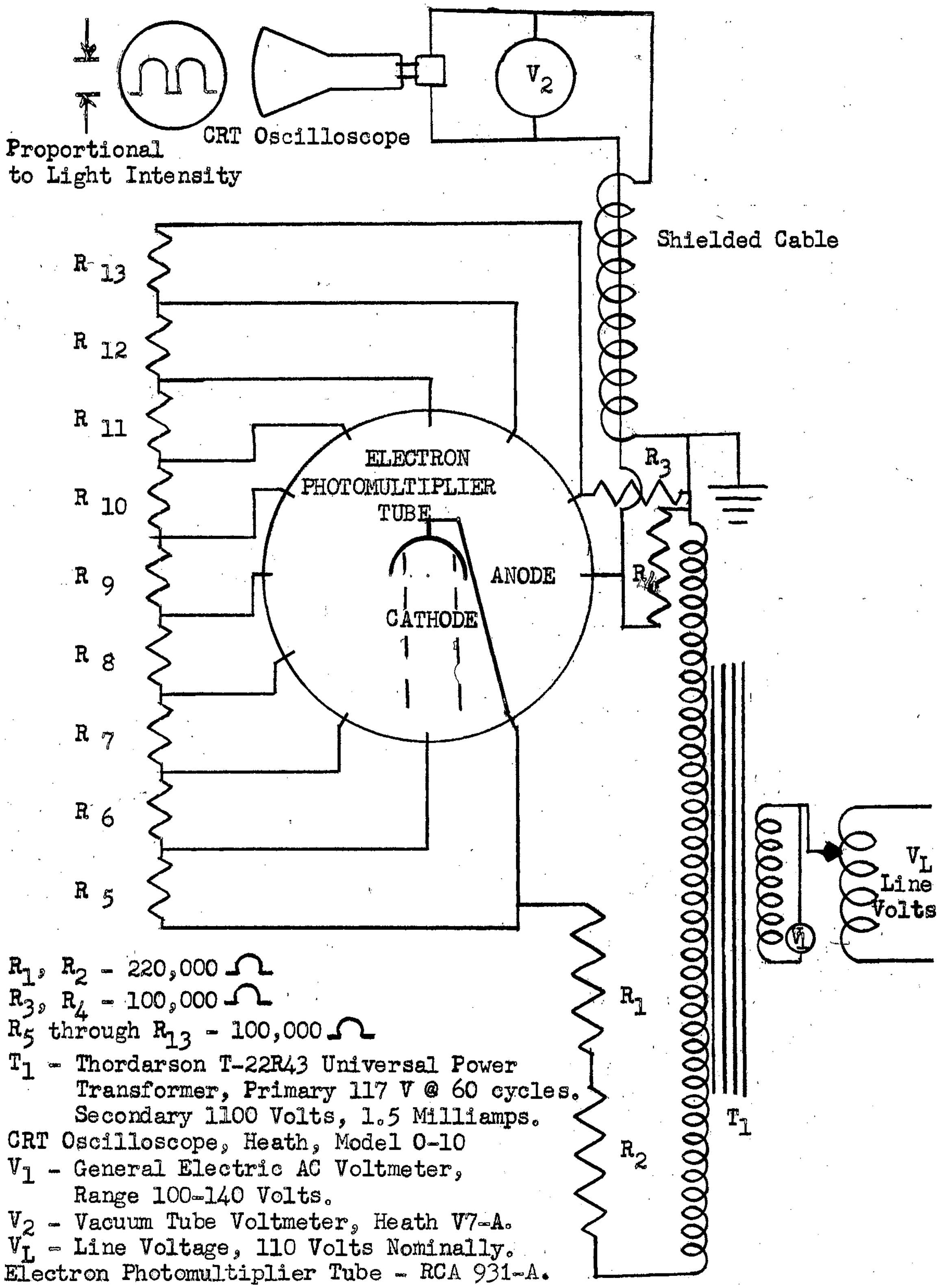
FIGURE 2. SCHEMATIC DIAGRAM OF NEPHELOMETER

Because only relative light measurements of scattered light intensities are needed, no attempt was made to measure absolute illumination values. This allowed wide variation in design possibilities for the circuit. Since a source of one thousand volts direct current was not available, this voltage was obtained in alternating current by a transformer from one hundred ten volts line voltage. As can be seen in Figure 3, Circuit Diagram of Photometer, the voltage drop of approximately one hundred volts per stage of the phototube was obtained by resistances between each stage.

By use of alternating current powering the phototube, the following advantages were obtained: (A) The output of the phototube was pulsating direct current which was sensed, displayed and precisely read on a cathode ray oscilloscope which eliminated the need for direct current instruments. (B) Output could be amplified by a preamplifier with little background noise. (C) No rectifiers or filter capacitors were needed in the power supply, providing safety to the operator from high voltages. (D) The unit was compact.

The phototube, with circuitry, was placed inside a large cylinder, seen at the left side of Figure 1. This was arranged to provide entirely dark surroundings for the phototube and to keep it cool. Both of these conditions were necessary for operation at extremely low electrical noise levels of background voltage from which the light amplification is made. For cooling, the main consideration was to keep heat, produced from the transformer, away from the phototube by using a centrifugal fan to blow the air in from the top.

Dark surroundings for the phototube were provided by painting the interior of the tube and all the surrounding nephelometer black.



R_1, R_2 - 220,000 Ω
R_3, R_4 - 100,000 Ω
R_5 through R_{13} - 100,000 Ω
T_1 - Thordarson T-22R43 Universal Power
Transformer, Primary 117 V @ 60 cycles.
Secondary 1100 Volts, 1.5 Milliamps.
CRT Oscilloscope, Heath, Model O-10
V_1 - General Electric AC Voltmeter,
Range 100-140 Volts.
V_2 - Vacuum Tube Voltmeter, Heath V7-A.
V_L - Line Voltage, 110 Volts Nominally.
Electron Photomultiplier Tube - RCA 931-A.

FIGURE 3. CIRCUIT DIAGRAM OF PHOTOMETER

The centrifugal fan blower was painted black to keep light from entering providing a dark interior with ventilation. The lower opening was covered with a surrounding oversize shield as a light-trap double baffle preventing the entry of light from the bottom.

The phototube was supported on a chassis in the center of the cylinder, around which air could pass. For restricting view of the light scatter, a pipe was placed from the phototube to the scattering chamber. Travel down the pipe may have attenuated the light, but it provided a selective sampling. The distance from the dust cloud to the phototube could be varied, permitting selection of the scattering area intercepted and intensity of the signal from the phototube.

It was necessary that too high a signal did not reach the phototube as it had definite saturation values above which it would measure no more increase in light intensity. The tube between the photometer and scattering chamber was seven feet long. A large size protractor was laid out on the tables used to support a tray holding the light source. The protractor had a radius of forty inches. The zero degree angle was placed in line with the photometer tube. Each of the tables were levelled to provide no vertical angular change in the light source. This provided accurate angular measurement each one-half degree.

The light source was a commercial slide projector with parabolic reflector behind the bulb. It was a source with filament about one-half inch square with heat collecting plate and lenses for narrow angle divergence. The five hundred watt tungsten filament bulb had restricting shields to produce a narrow angle beam which reduced the light intensity. The first light restricting shield was built with three parallel slits from a black surface so that all but the parallel light would be kept from passing through the circular slits. Since the lower angle limit of the parallel slit tube was 12.5°, another tube was built with only one shield and a narrow tube twelve inches long.

This second low-angle shield was used to measure to 5° back scatter angle, the low angle limit because of the distance between light source housing and phototube restricting tube. The upper limit was imposed by the wide light beam which reflected light down the phototube restricting tube above 171.5° back scatter angle. Between extreme limits, only the range from 75 to 100° was cut out because of the supports holding the outer cylinder.

To obtain variance of frequency, color filters were used over the light source. Colored DuPont Cellophane was used as the filter. From range of higher wavelengths, colors used were white, red, yellow, green blue and violet. Cellophane transmits some of all frequencies besides its color. These filters were placed in the slide chamber of the light source, the slide projector. Solenoid operation was used to change the slide color filters by push button control when testing.

This experiment used a nephelometer which had the whole circular dust cloud illuminated and scatter intensity sensed from the whole cloud by admittedly divergent beams. This was the first application of this system. It was represented symbolically in Part A of Figure 4.

Previous nephelometers use and theoretical developments assumed use of sensing a small increment scatter element. The traditional interpretation of this element was shown by the dotted line sensing

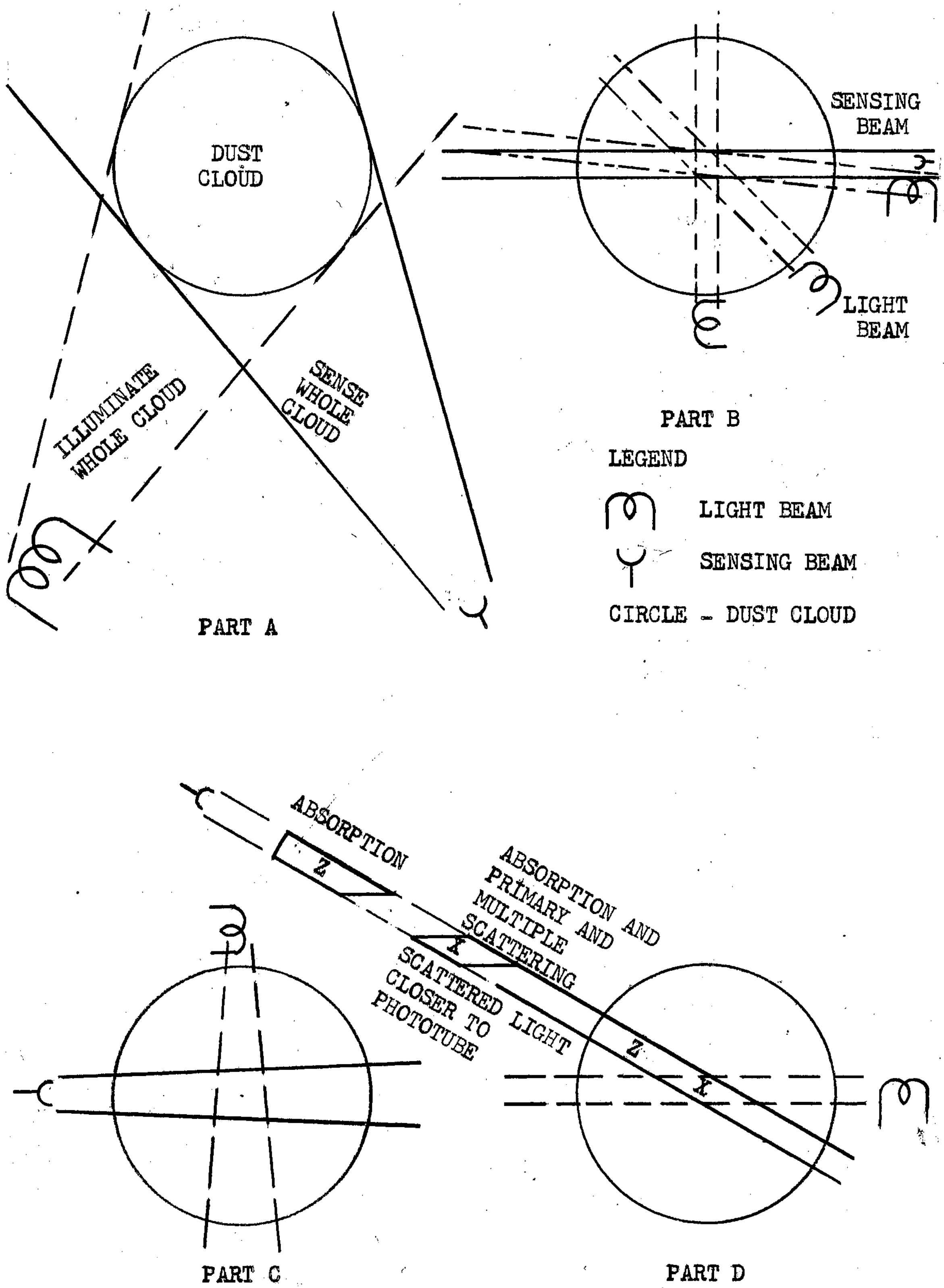


FIGURE 4. OPTICS OF THE NEPHELOMETER

area in Part B, Figure 4. It is impossible to attain these parallel beams. Slightly divergent light and sensing beams, Part C, Figure 4, produce a scattering area in the shape of an irregular polygon. Calculation of this area is difficult. Since the area changes with angle, it would have to calculated for each angle. Each scatter intensity value would then be multiplied by an area factor. The only method of eliminating a changing increment area is the method used by Waldram (27) of off center mounting of parallel plates to narrow the beam width as the angle lowers.

A small angle limitation is reached in increment sensing as is shown by the dotted line in Part B. When the intersection of the two beams exist outside the dust cloud, the ends of the parallelogram intersection are cut off. Calculation of this area would necessitate reducing the parallelogram area by the acute end area of the parallelogram cut off by the arc of the dust cloud.

Finally, probably the biggest variable added, impossible to calculate with present theory, was that presented by absorption and multiple scattering of the particles. Graphical description is shown of these items in Part D, Figure 4. The photometer from sensing an increment of the dust cloud, recieves a light scatter value which varies from one side to the other of the beam width. As most phototubes have different sensing characteristics in different parts of the beam width, another angular variable is introduced.

In comparison to increment sensing, the whole cloud sensing of this experiment reduces the possibility of unwanted variables. Expecially for an aerosol easily confined to circular area with scattering from particles in the cloud more intense than dust in air, as is field dust, the whole cloud sensing will be superior.

For sensing by polarized light, a Tiffen Polaroid Filter was placed over the phototube tube.

V. PROCEDURE

The experimental observations were designed to reliably produce a low-angle back scatter graph. The method was to obtain data for one graph at a time by testing each angle consecutively.

Variation in experimental results was to be expected from; (A) fatigue of the phototube; (B) lowering intensity of the light source and (C) varying back scatter from differing random distribution of the many dust particles. This last factor was expected to be more pronounced in the polydisperse dust than in sized samples.

The first two variables, changing characteristics of the beams, were thought to be able to be resolved by changing testing techniques. Their effect was isolated by starting one test at one angular extreme. One test run would start at a low angle, progressing chronologically through the angular values. Next a test run would start at the high angular value receding down the same angular increments as the first test. Comparison of these two test sequences were thought to be able to show the effect of changing beam, phototube and light source characteristics.

Since main interest in the tests was to determine relative values of angular scatter intensity, effect of the first two variables in changing the absolute angular values of each test should not obscure the determination of maxima and minima. The remaining variable was the particular light scatter variance from size distribution of dust particles. This variable could only be isolated by test replications. After indication of the maxima and minima areas, more test replications would be made in these areas.

For graphical analysis, the number of test run replications were determined by obtaining enough tests to determine variability of factors not related to angular scatter intensity within the limitation of available time for the tests. This number of tests should determine the relative maxima and minima of angular scatter. For this experiment, four to seven test run replications of each test condition were made.

Since two light restricting shields were used, tests with each were made at separate times. The shield for low-angle scattering had less illumination intensity than did the parallel slit shield for larger angles. These two shields produced a return voltage from the phototube of different magnitudes. To enable comparison of angular scatter intensity obtained by these shields, the angles measured by the low-angle shield overlap the other shield a few degrees to provide a basis for finding a factor to multiply by one to compare with the other.

Procedure for one test run was to begin at 12.5°, the lower limit for the parallel slit shield. The sifter would be filled with dust and the line voltage observed. The background noise return from the phototube would be recorded before the test was begun to ascertain normal operating conditions. This noise is the characteristic of an electronic amplifying circuit causing it to produce an output from variables not related to the signal being amplified. The background noise level varied ten times the line voltage change and from other factors not fully understood. This variation could also have been caused by a changing characteristic of the phototube or impedance of the supply voltage.

After energizing the sifter, one person would watch the voltage return from the phototube until it reached a stabilized upper value, usually in three to five seconds. Phototube return values were recorded when they were not obviously erroneous by fluctuation of line voltage.

If there was any reason to believe other variables entered into the test, it was repeated for the same angle. Reasons would be fluctuation of line voltage during the test or a voltage return to phototube which did not stabilize at any value. After the voltage return from the phototube was reliably observed, whether in one or several tests, the light source was moved to the next consecutive angle. The test runs were repeated for each condition of light frequency and sized dust.

For tests of polarized light, a polarizing filter was placed over the phototube tube. At different back scatter angles, the filter was rotated through the whole range of polarizing angles. During the constant dust cloud concentration of one test, rotating the polarizing filter showed any angle effect in diminishing back scatter. This angle was measured with a protractor referenced to vertical on the phototube tube.

The dust fallout tests were made by stopping the dust sifter after five seconds of dust discharge from the sifter. Readings of scatter intensity were made each second after start of the test for several minutes to show remaining scatter from dust suspended in the air at 171.5° back scatter angle.

VI. PRESENTATION OF RESULTS

The Appendix is a presentation of all data obtained in the experiment. Since interpretation of these results was difficult from tabulation, most of them were displayed graphically on figures. Each complete angular scatter test run represents consecutive angle measurements through the range selected for that test.

Since there are other variables causing test trend changes, evaluation of test data will be by comparative test run characteristics. The graphs were drawn with lines connecting points of each test run. The lines connecting the points are not meant to infer scatter values for angles between the measured angles.

The lower limit of the parallel slit light restricting shield was 12.5° because at lower angles, it cut out sensing area of the phototube. Test runs of the parallel slit shield were made from 12.5° to 60°. The low-angle shield runs are presented from 5° to a few degrees above 12.5°. Because of reduction in intensity of the beam by the low-angle shield, an adjustment factor was multiplied by the results of the low-angle tests to facilitate comparisons of the two types of tests. Phototube return values from the parallel slit shield were divided by values from the same angles for the low-angle shield which were overlapped in the tests. Each of these overlapping angle ratios were averaged producing the adjustment factor.

The results were graphed for back scatter angles 5° to 25°, the area in which minima of scatter would be most likely applicable as a problem solution. Other graphs for these lower angular ranges were for comparison to other experimental results. The ordinate was scattering angle intensity measured in voltage across the load of the phototube. Each figure included tests of the same light frequency and dust size.

The first three test condition results, Figures 5, 6 and 7 represent tests of white light on sized dust samples. The symbols around the graph points (○, ⬡, △, ◇, ▽, □, ▷) represent the same test sequence for each figure. The last six figures, 8 through 14, are tests of various light frequencies on the polydisperse dust cloud. As with Figures 5, 6 and 7, each graph designator indicates the same test sequences as the other sized dust tests.

Graphs comparable by direction of angular test sequence are connoted by a small arrow (⟶) which appears next to the graph. An arrow pointing up the angular scale represents a test run started at the low end of the back scatter angles moving through each consecutive angle to the maximum angle recorded. The downscale arrow represents a test run started from the upper end of the same angular limit down the same angles to the low angular values.

The remaining tests, when obtained, square (□), inverted triangle (▽) and side triangle (▷) are tests of angles in the region of minimum scatter indicated in previous tests. In many cases, angles were measured in half-degree increments for more accurately determining minimum scatter.

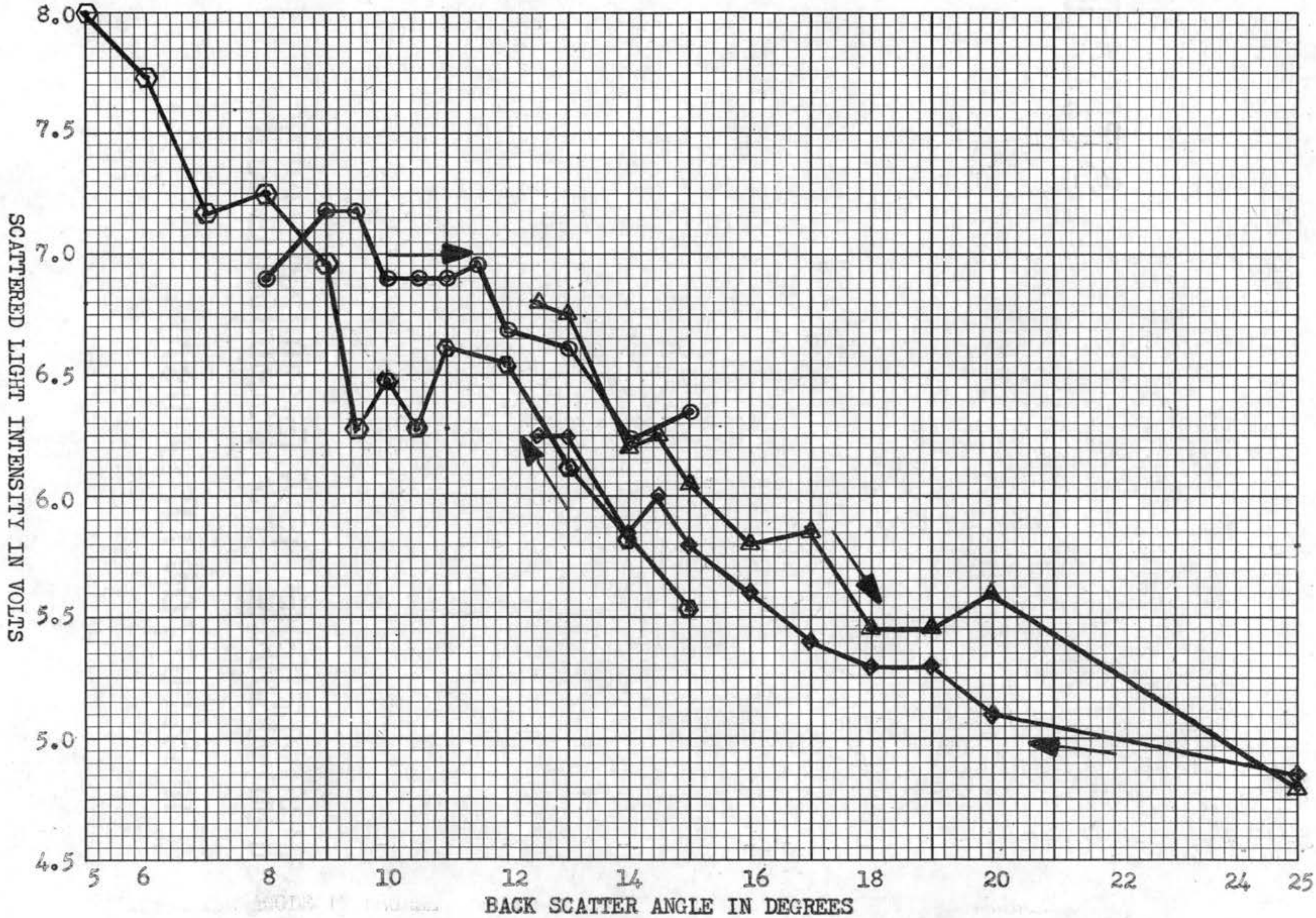


FIGURE 5. WHITE LIGHT BACK SCATTER TESTS ON DUST 105 TO 74 MICRONS

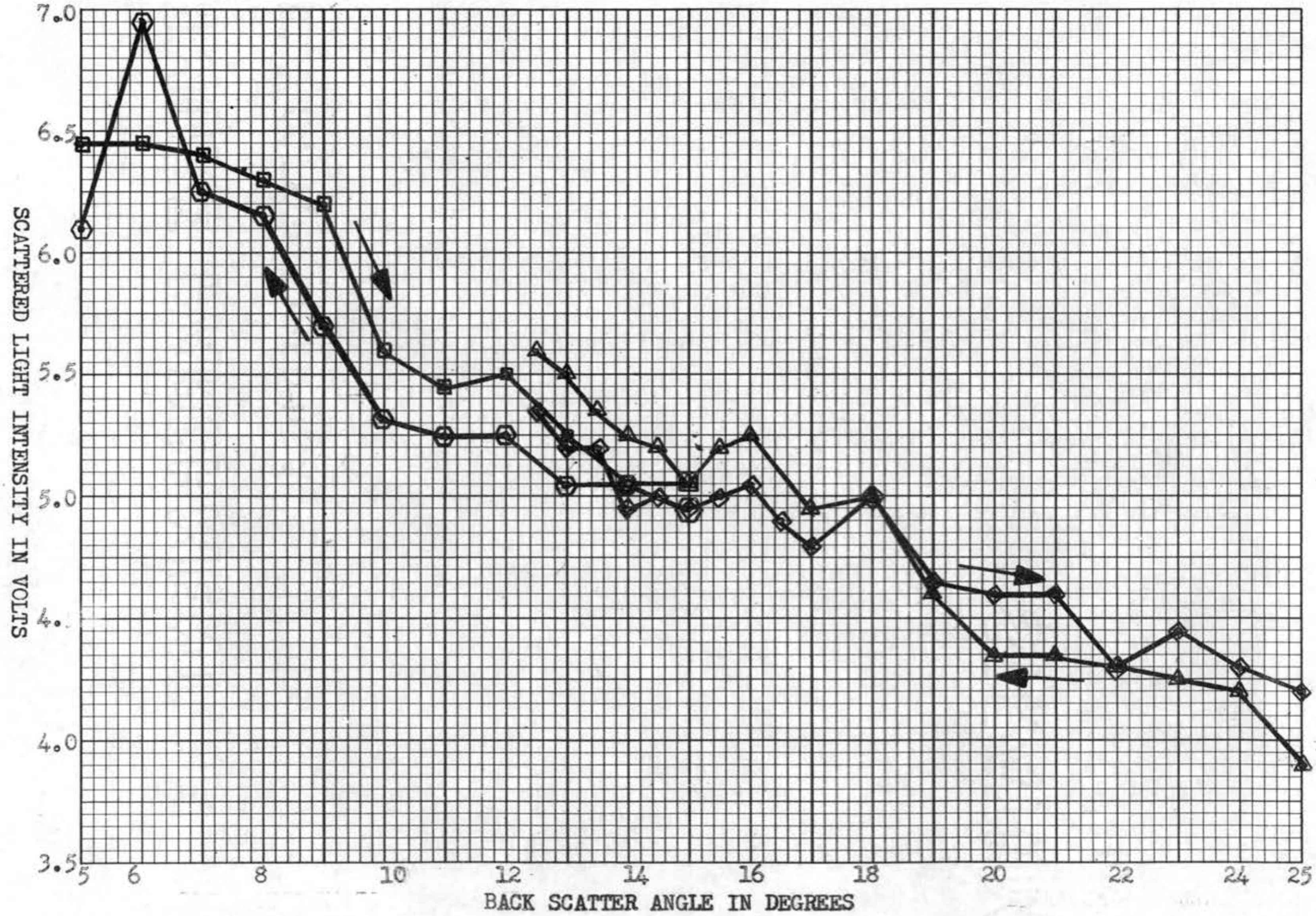


FIGURE 6. WHITE LIGHT BACK SCATTER TESTS ON DUST 74 TO 53 MICRONS

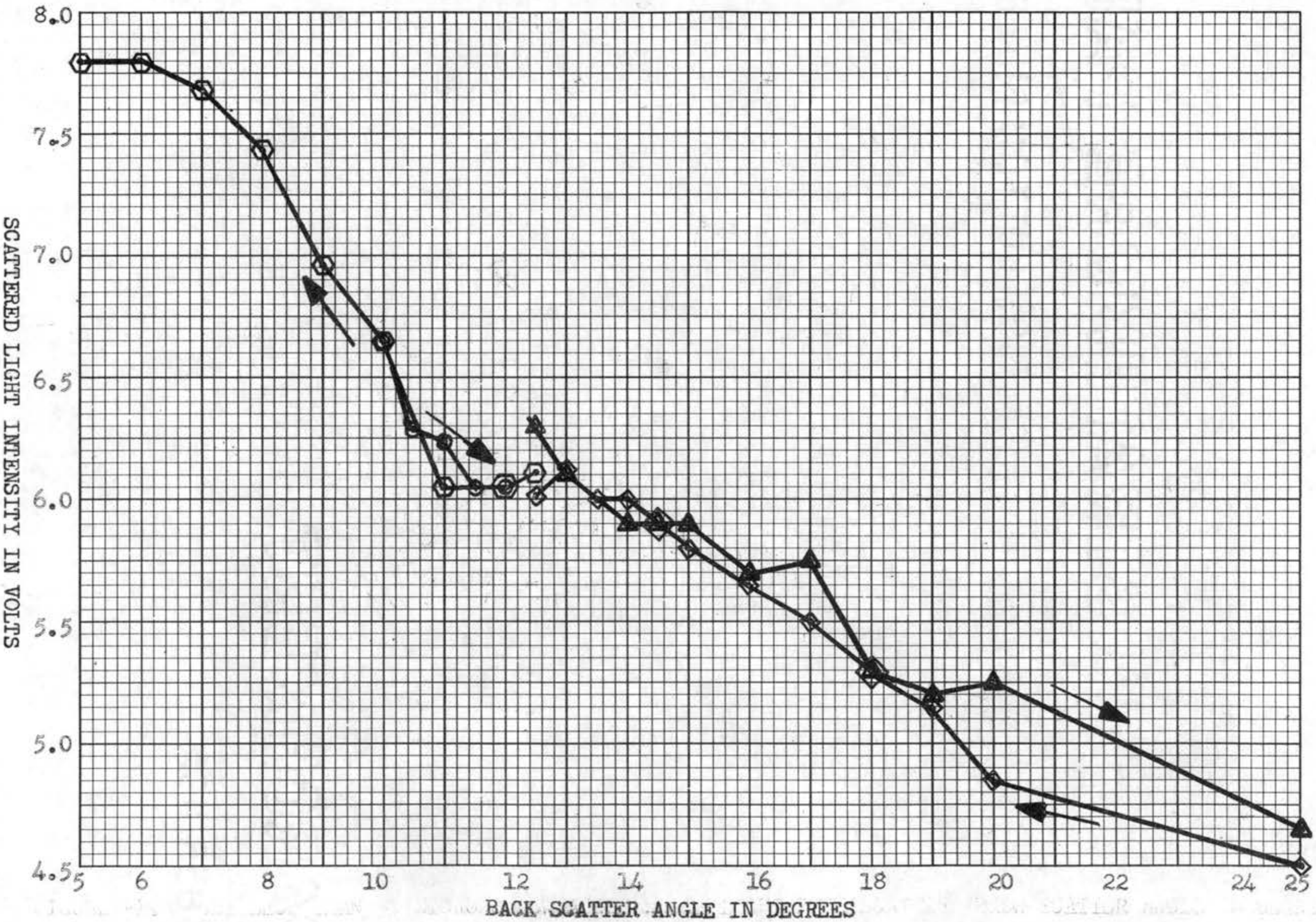


FIGURE 7. WHITE LIGHT BACK SCATTER TESTS ON DUST 53 MICRONS AND BELOW

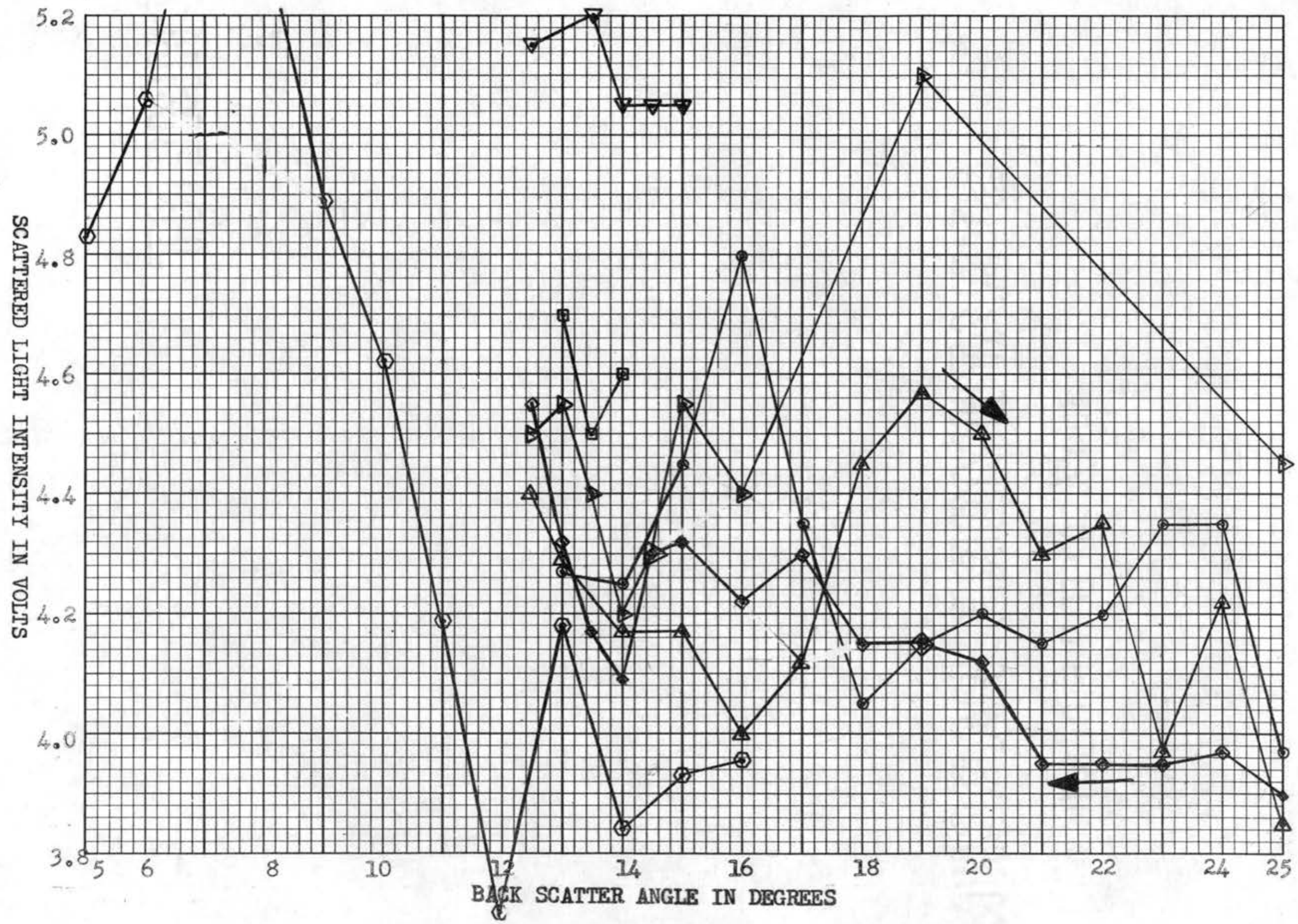


FIGURE 8. WHITE LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

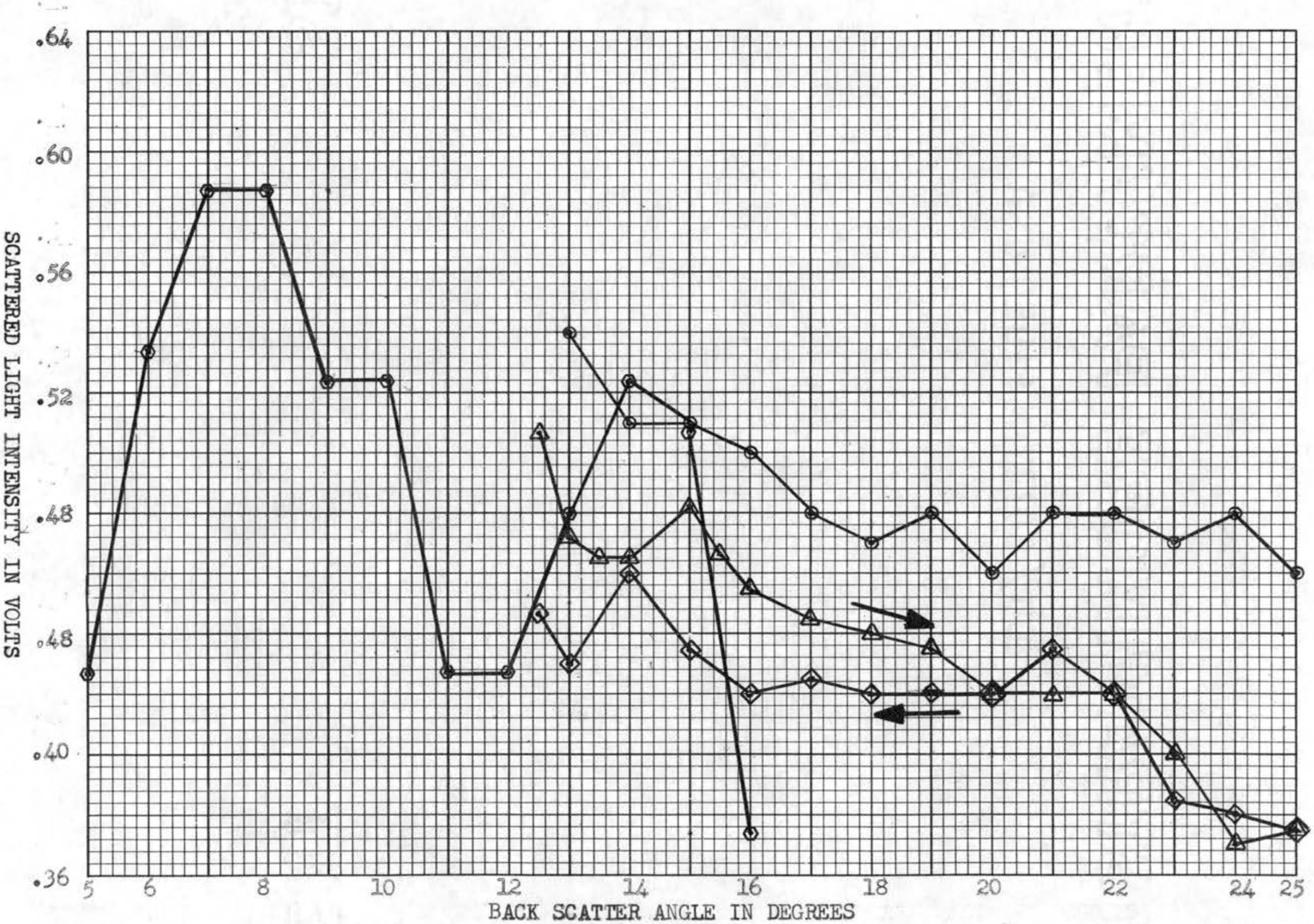


FIGURE 9. RED LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

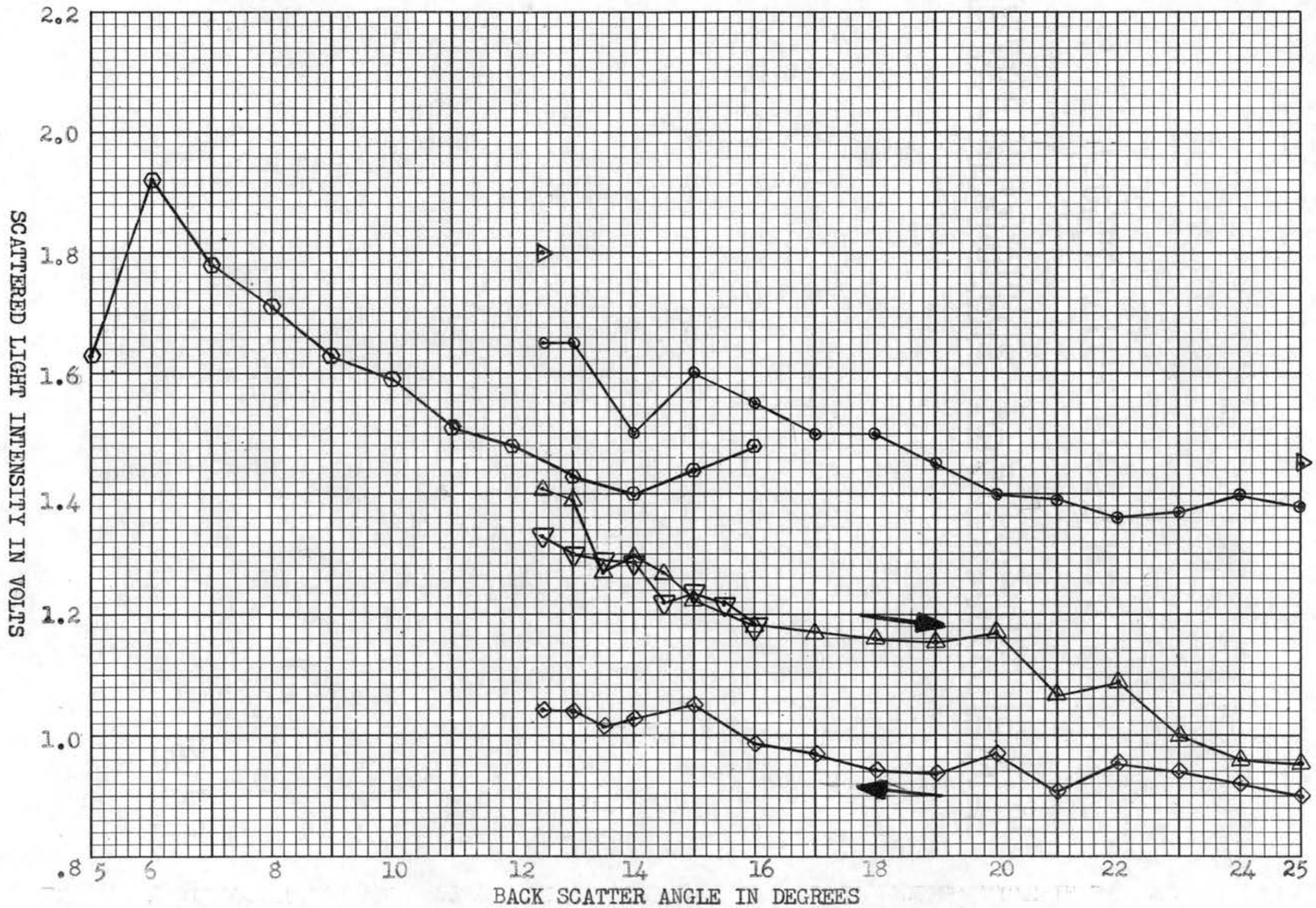


FIGURE 10. YELLOW LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

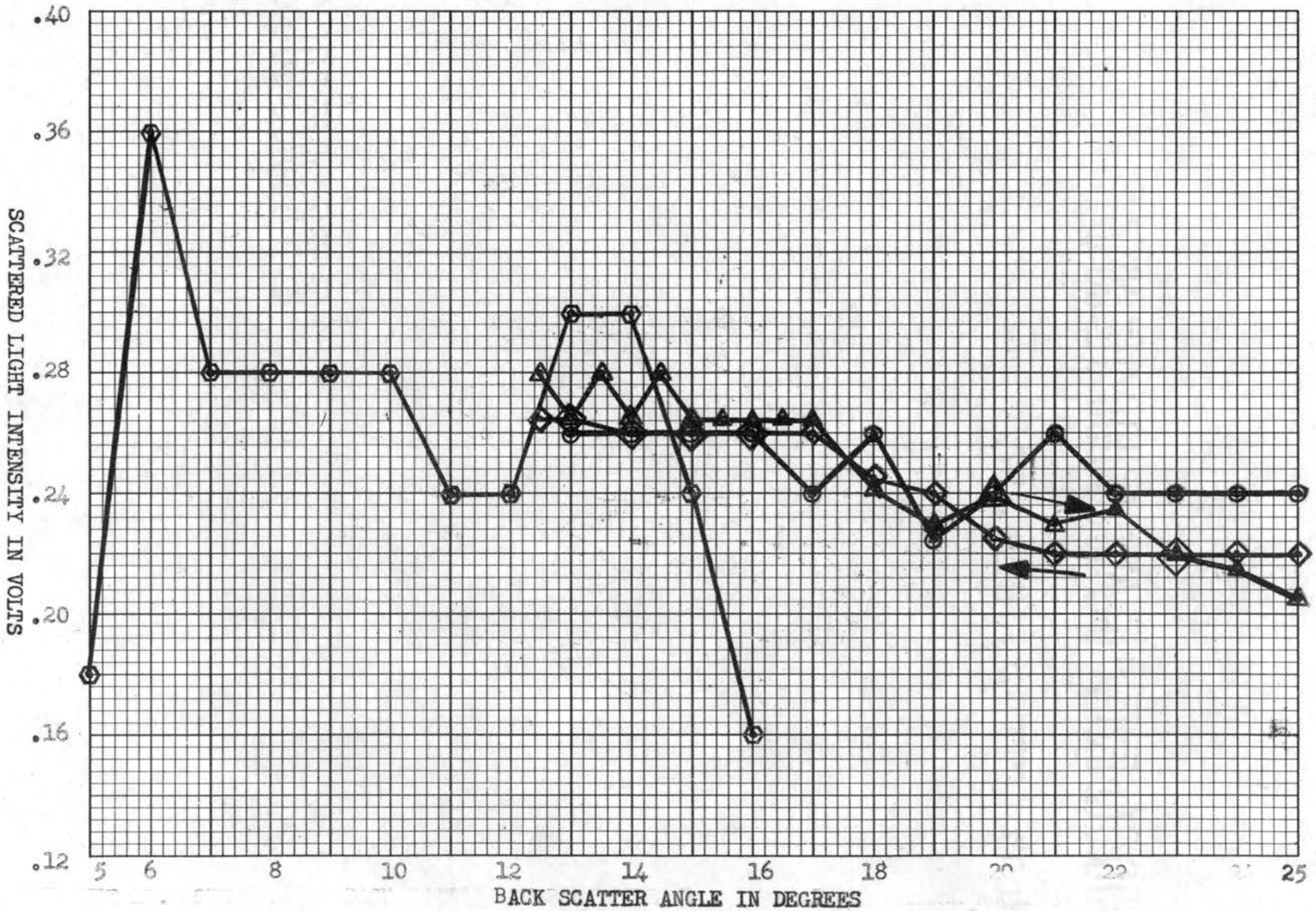


FIGURE 11. GREEN LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

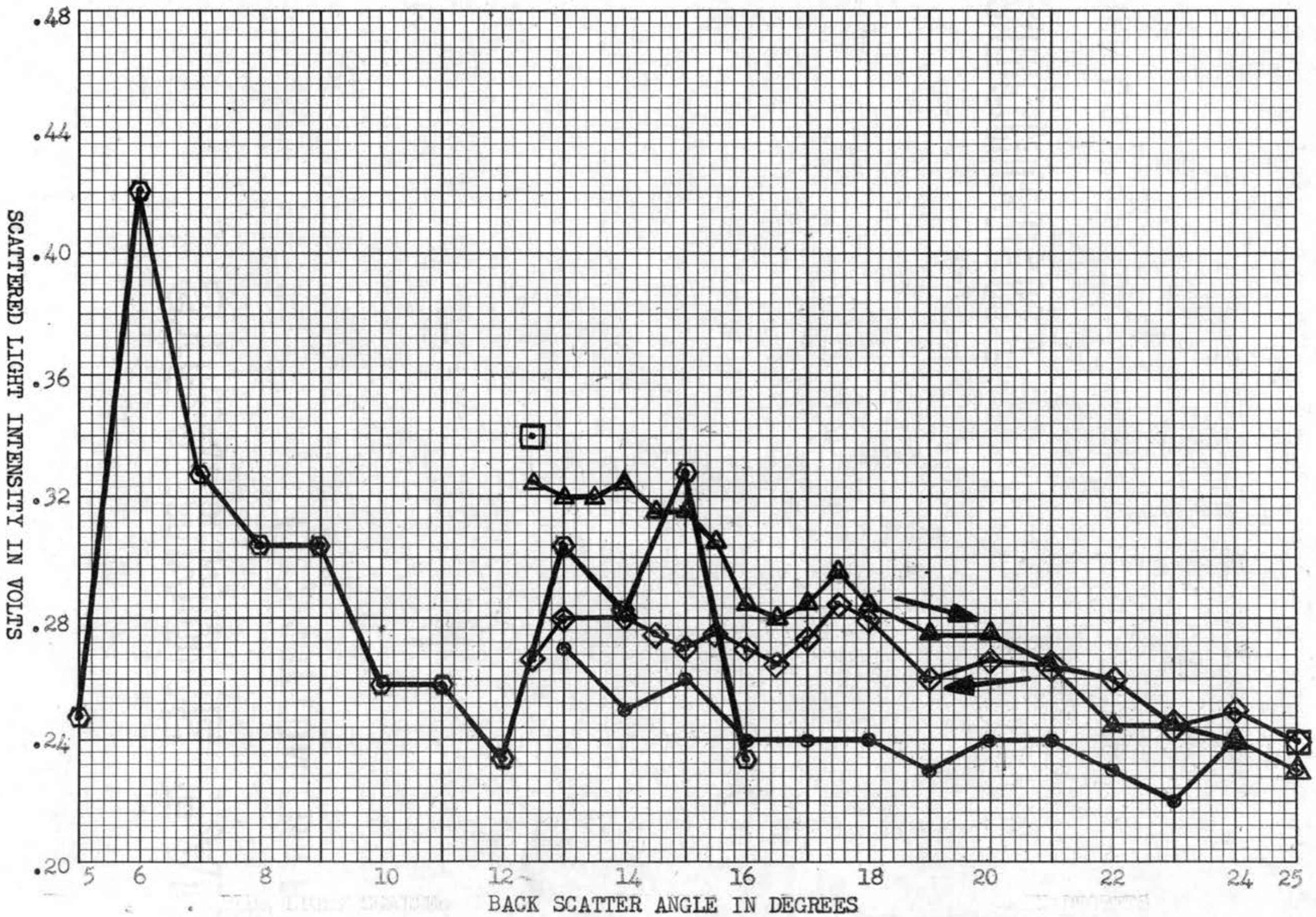


FIGURE 12. BLUE LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

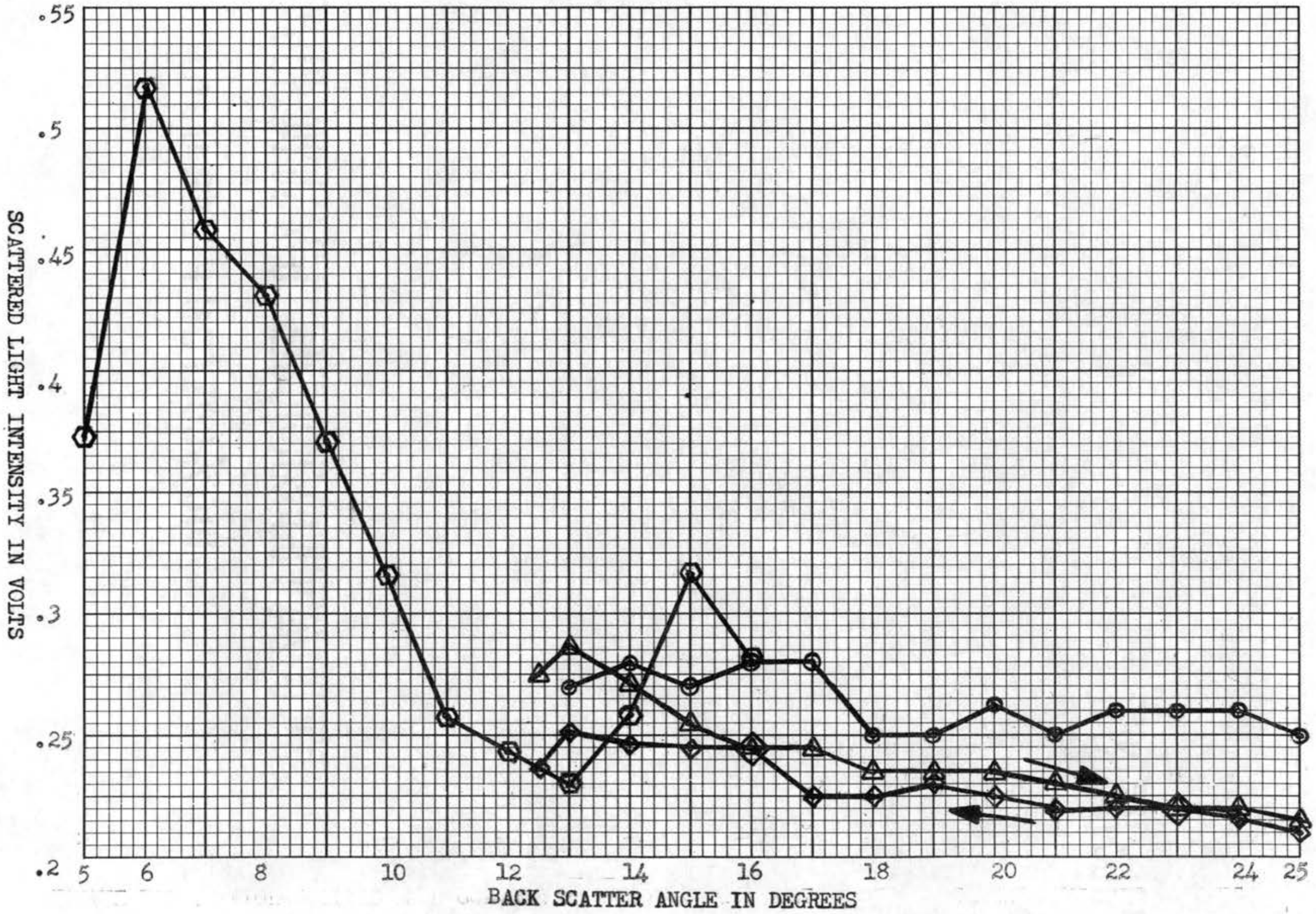


FIGURE 13. VIOLET LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST

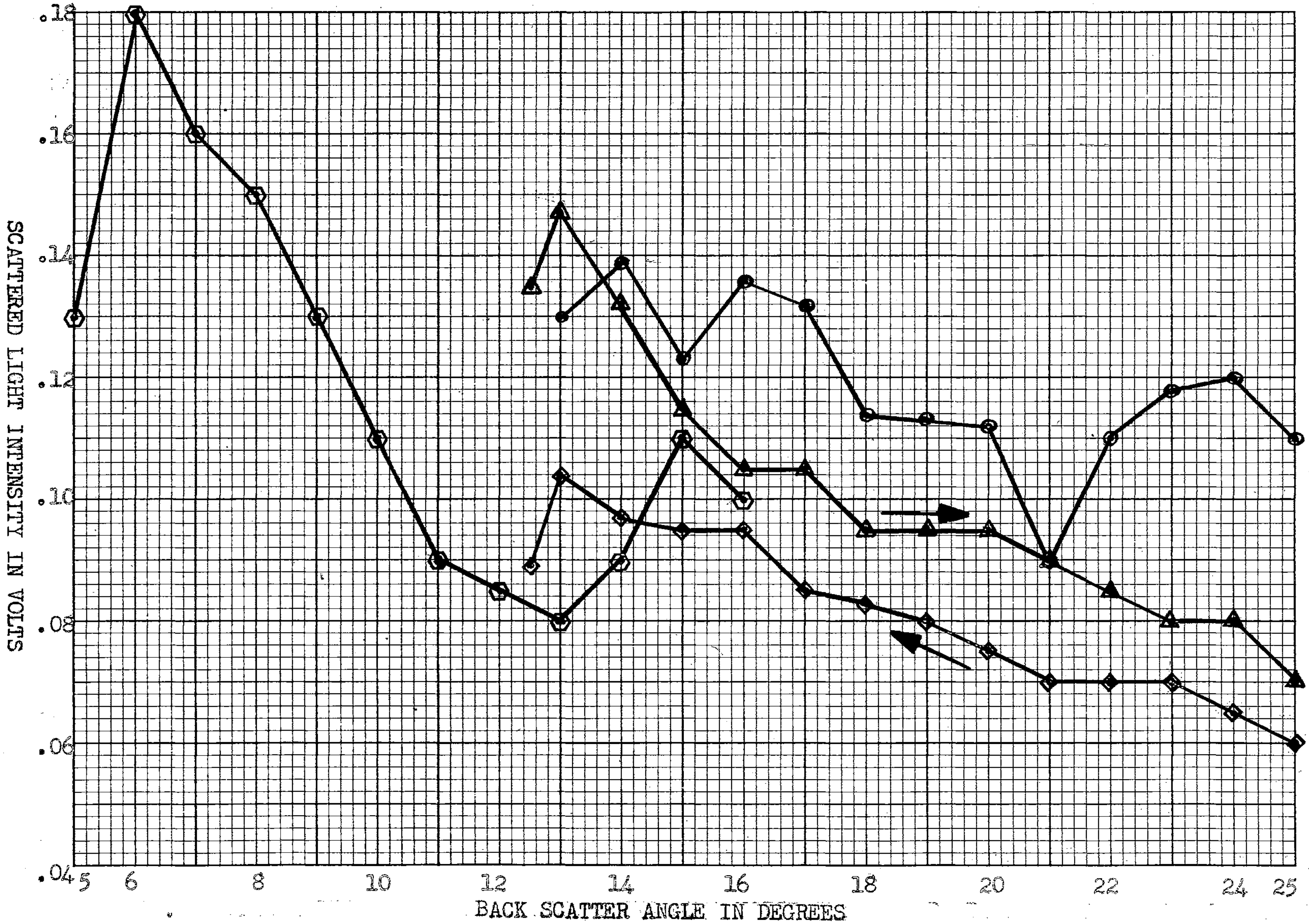


FIGURE 14. VIOLET LIGHT BACK SCATTER TESTS ON POLYDISPERSE DUST
WITH BACKGROUND NOISE VOLTAGE SUBTRACTED

Table II presents the summary of indications of the minimum near 14° back scatter angle. To obtain Table II, the problem of finding back scatter minimum values for each test condition was examined. Characteristics of minimum scatter were noted, especially in angles most applicable to problem solution.

A minimum of scatter intensity appears as a graph value which has higher values to each side of it. Because of experimental variables, minimum tendencies are defined as a graph presentation, which, while not a minimum, tends toward it by having a higher value to one side with the same value to the other side. Minimum tendencies are only identified when another graph produces a minimum in the same place. A variable minimum is the average of angular minimum scatter intensities over a small range of angles for one test condition.

Confidence of minima is affected by number of tests confirming the indication and pronounced nature or extent of values. Any characteristic only supported by one test is not as reliable as multiple indications of several graphs.

Graph results show a decrease of angular back scatter intensity for all but the green light test condition over the range of five to twenty five degrees back scatter angle. Separate test runs show many minima and maxima of back scatter intensity. The variability between test runs, however, lends little confidence to picking certain back scatter minima.

Only at one area, from five to twenty-five degrees back scatter angle, are test minima numerous and consistent enough to identify as a probable back scatter minimum. First test runs established

TABLE II

SUMMARY OF LOW BACK SCATTER MINIMUM INDICATIONS

FIGURE	TEST CONDITION	CHARACTERISTIC MINIMUM In Back Scatter Angle Degrees	TYPE
	SIZED DUST WHITE LIGHT		
5	105-74 Microns	14°	Pronounced, not extreme.
6	74-53 Microns	None	
7	Less Than 53 Microns	None	
	VARIOUS FREQUENCIES POLYDISPERSE DUST		
8	White	14°	Pronounced, sharp peak.
9	Red	13.5°	Slight and variable. Masked by maximum at 14.5°.
10	Yellow	13.5°	Variable.
11	Green	None	
12	Blue	14.5°	Variable.
13	Violet	None	

this area as more consistently producing a minimum than other areas. Later tests concentrated in this area further supported the minimum and showed test conditions to which it was most applicable.

Figure 5 shows a minimum back scatter angle at fourteen degrees which is pronounced in three graphs but not indicated in one, the hexagon (⬡) designation. The hexagon designated graph does not have a scatter measurement at 14.5° which determined the minimum for two of the other graphs.

Figure 8 shows more variation between tests than did Figures 5, 6 and 7 because it contained a wider range of dust sizes. Figure 8 includes most test runs because of the interest in characteristics of white light. All graphs of Figure 8 show at least tendency of minimum scatter at 14° back scatter angle. Four of the graphs show a pronounced minimum at 14°. One of them shows a minimum at 13.5°. Two of the graphs indicate only tendency minimum values because the triangle (△) and inverted triangle test runs do not show an increase in value on the right side. Figure 8 is then characterized as having a pronounced, but not extreme minimum back scatter angle intensity at 14°. The same procedures were used for arriving at indications from all the graphs.

Inconclusive results, particularly of the green and violet light sources suggest that some other basis of comparison should be used. Since the back scatter angle intensities of higher frequency colors were so low in value, they often amounted to a reading as small as twice the background noise voltage level. These can be compared from data in the Appendix which shows the background noise voltage with each test result.

The background noise level of the phototube circuit varied from unknown factors which may have had some relation to the light scatter values. It may seem reasonable to subtract from the light back scatter angle values, the background noise levels of the phototube. For other high frequency colors, this subtraction would not produce noticable effects because of constance of background noise levels, but for violet light, the background noise values varied over a large range.

Figure 14, Violet Light Back Scatter on Polydisperse Dust With Background Noise Voltage Subtracted was made to find the effect of subtraction of background noise level. Effect of subtraction of this background noise is found by comparison of Figure 14 with Figure 13, Violet Light Back Scatter Tests on Polydisperse Dust.

Figure 15, Polar Scatter Diagram for White Light on Polydisperse Dust, was one test of the full range of the nephelometer for comparison to other tests. The test data for the large angle range test is shown by the side triangle (▷) designators with angles below 12.5° marked by hexagon (⬡) designators. The change is shown because it is the addition of another test, the low-angle shield test.

Further summary of results is presented in Figure 16, Results of Color Frequencies Light Back Scatter From Polydisperse Dust. It was prepared from one test for each frequency in which there were numerous tests to 60° back scatter angle. Comparison of filter action of colors and curve characteristics can be made from it.

The result of sensing by polarized filter produced no change in scatter intensity of back scatter angles below 60° as is shown in the Appendix.

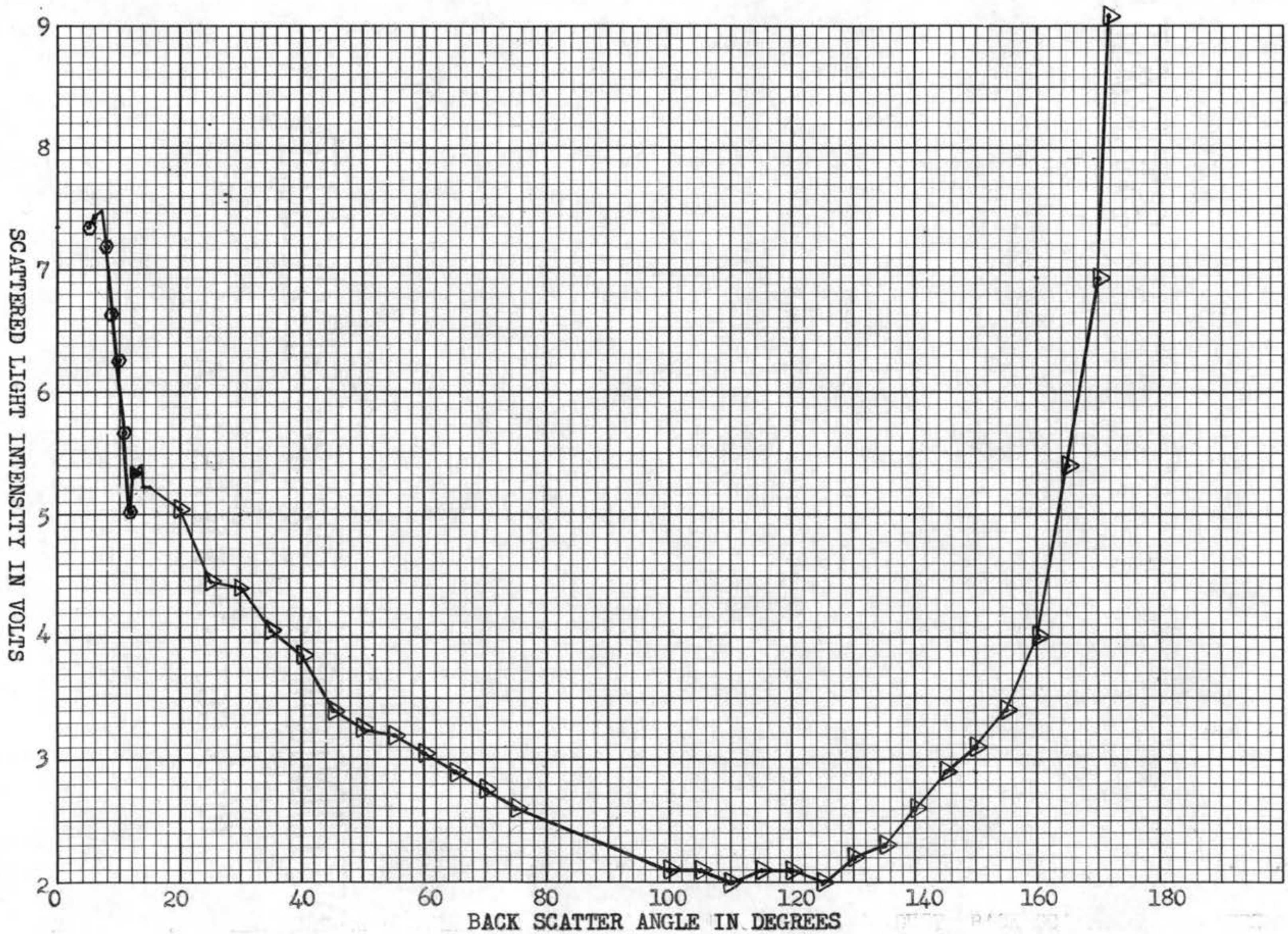


FIGURE 15. POLAR SCATTER DIAGRAM FOR WHITE LIGHT ON POLYDISPERSE DUST

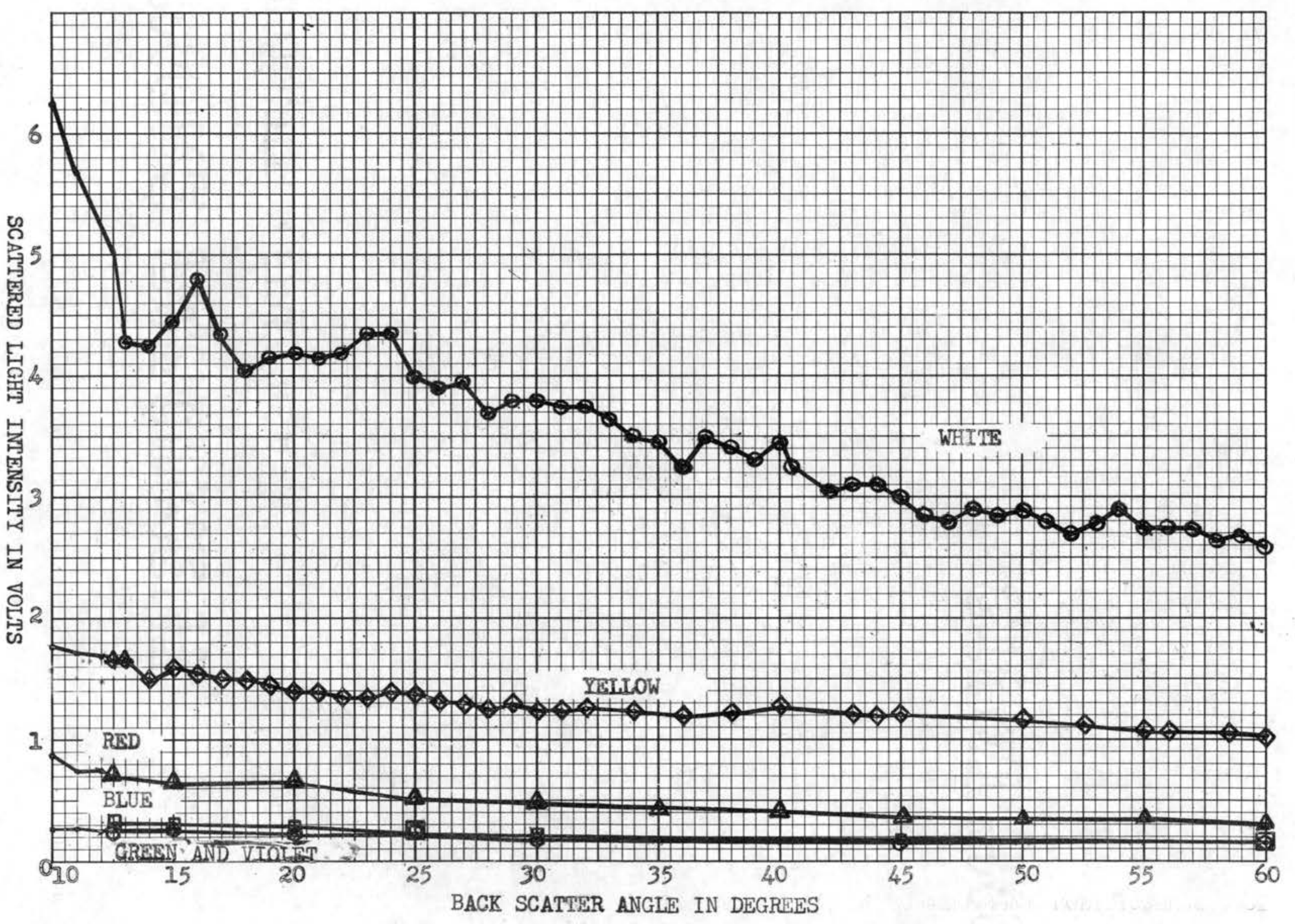


FIGURE 16. RESULTS OF COLOR FREQUENCIES LIGHT BACK SCATTER FROM POLYDISPERSE DUST

Figure 17, Particle Fallout From Polydisperse Dust Measured at Back Scatter Angle 171.5 Degrees, was a test to show settling of particles. It shows three fallout tests which were taken of dust after the sifter was stopped in five seconds after time of starting. The further scatter intensity, after five seconds, represents fallout of particles from the air. It is noted that intensity increased after termination of test.

The data in the Appendix includes a listing of each separate test for which the light source was moved to a new position. Each column is a different test run. The background noise voltage (v), is shown with the phototube scatter return (V). The values of phototube scatter return were averaged for entry on the graphs when they represented tests of the same angle. Repeating the same test was only done when first starting a test run for determining stabilized operation, when line voltage was fluctuating or when background noise of phototube output was fluctuating. In the Appendix, after scatter values for sized dust and light frequency parameters, results from the polarized filter test are presented. Next is shown the voltage readings for times after the dust cloud was stopped representing fallout of dust.

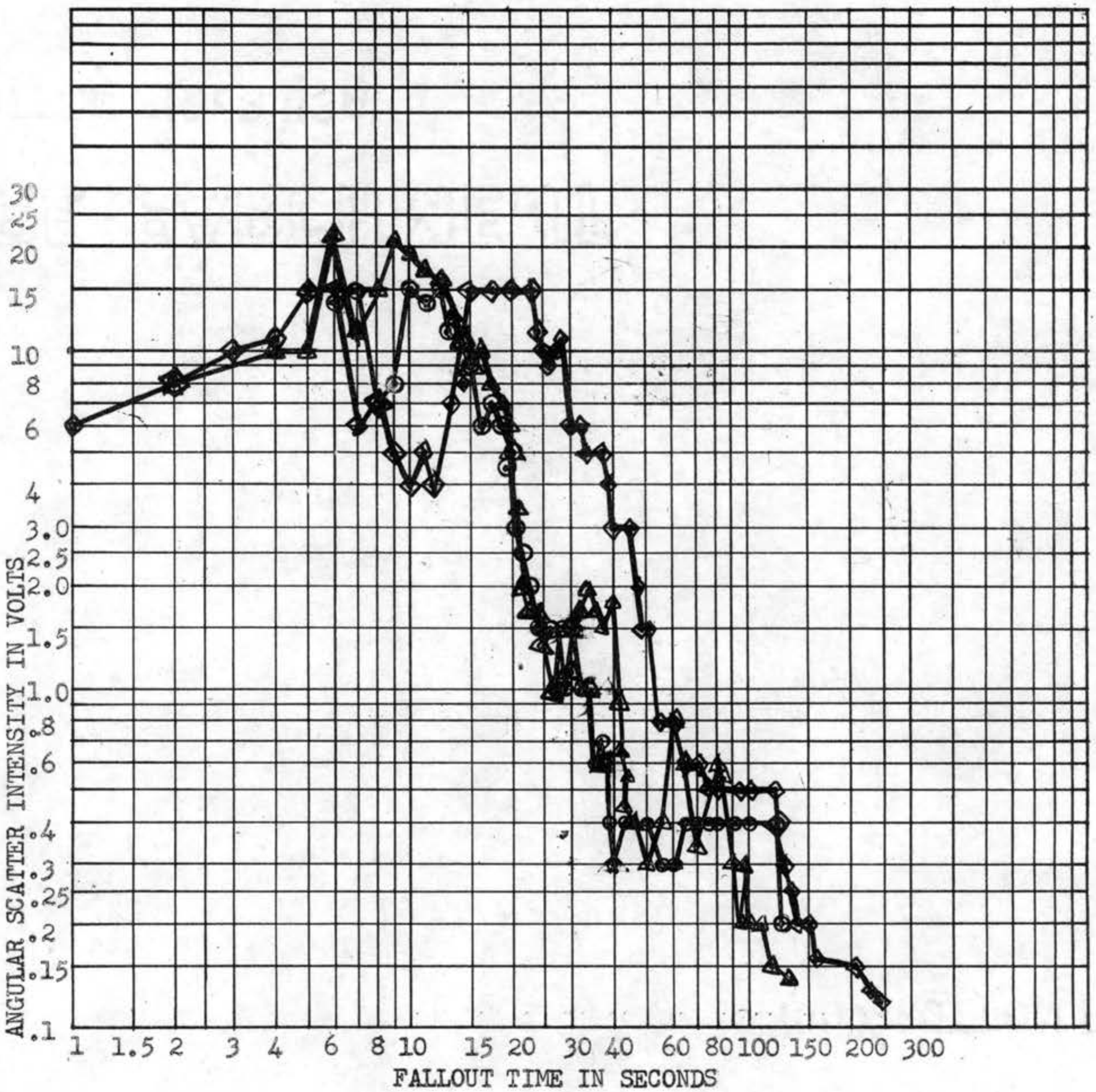


FIGURE 17. PARTICLE FALLOUT FROM POLYDISPERSE DUST MEASURED AT BACK SCATTER ANGLE 171.5 DEGREES

VII. INTERPRETATIONS OF RESULTS

A. Discussion of Results

The use of a narrower band of frequencies of light than white light produces little indication of pronounced minima or other characteristics of angular scatter which would directly minimize back scatter. The higher wavelength frequencies, red and yellow, contribute more of the scattering variation than do the low ones, blue and green. However, this is not judged conclusive proof because of the questionable reliability of the low wavelength frequency tests. This is questioned because the color filters for filtering the low frequency sources left such a small source light intensity. This low intensity source necessitated the recording instruments be read at their most unreliable positions, maximum amplification with minimum indication.

Table II shows 14° back scatter angle as a minimum scatter intensity for several test conditions. Tests of narrower ranges of wavelength, the color tests, generally support the white light relative angular scatter results. There is no orientation of sifter parts or screen mesh of the nephelometer which would cause this 14° minimum.

Figure 14 shows a minimum scatter intensity at near 110° back scatter angle which compares closely to the results of previous investigations on atmospheric dust. The 110° minimum persisted for a much greater range of angles than the 14° minimum.

Other minima of back scatter intensity appear at 12° back scatter in many tests and at higher angles for fewer tests but these are not considered to have been indicated exactly enough in these tests to be reliable indications. Also minimums of back scatter intensity appear at 7° and 19° back scatter angle in many test runs but have not been established with enough confidence to call characteristics.

Possibility is indicated for a minimum back scatter angle below 5°, the minimum angle able to be tested by equipment in this experiment. Indications for it are only unreliably determined because of the few low-angle back scatter tests. Previous investigators did not detect the minima of angular light scatter of this experiment because they did not study dust particles this large or measure as small angle increments.

Data in the Appendix shows effects of sensing with polarized light indicating no change in back scatter below an angle of 60°. For low back scatter angles, it shows little application but it is a possibility for most complete elimination of back scatter at the minimum of the whole polar scatter scale, 110° back scatter angle.

Variation in results between tests of the same conditions is evident from the graphs. The triangle (Δ) graph designation represents the start of a test at the low end of back scatter angles with the parallel slit shield moving up to the maximum angle recorded. The diamond (◇) symbol is the record of angular values of a test immediately after the previous one moving from the top end of the same angular limit down toward the lower angular values. The change of procedure for the two tests under the same conditions reveals a lag of values from moving back down the angular scale.

Figures 4, 5 and 6, tests on sized particles, all show less absolute changes of angular scatter intensity than do the tests on polydisperse dust, Figure 8 through 13. A smaller size range would scatter more constantly in different tests than a more heterogeneous polydisperse dust because less variation of individual particle sizes causing more consistent scattering. This is in agreement with theoretical predictions of polydisperse scattering of Sinclair and La Mar and others.

The results indicate that for dust particles under 53 microns, no minimum of scatter intensity is evident other than one at 11.5°. Small particle sizes, below the maximum range of this experiment, considered to be 105 microns, apparently forward scatter more light than do the larger particles. This was noted when making tests for a polar scatter diagram on this polydisperse dust to compare with previous investigators. At the upper limit of scatter angles available, 171.5° back scatter angle, it was observed that after stopping the polydisperse dust cloud, the scatter became more intense. Also, there are several instances in which the scatter intensity increases in time after the dust begins fallout. This indicates that there are more types of scattering than primary scattering present.

Comparing figures shows that Figure 13, Violet Light Back Scatter Tests on Polydisperse Dust, has a slightly closer correlation of graph tendencies than does Figure 14, Violet Light Back Scatter Tests on Polydisperse Dust With Background Noise Voltage Subtracted. More tendencies appeared in Figure 14 which oppose each other for the test runs.

B. Conclusions

The test results are consistent and detailed enough to identify some relative angular light scatter characteristics.

Back scatter intensity generally decreases with increasing back scatter angle. There are small scale maxima and minima of angular back scatter intensity.

A possibility for minimum back scatter intensity is 14° back scatter angle with white tungsten filament light. This angle is the lowest reliable minimum of low-angle back scatter from this experiment.

Tests of various frequency tungsten filament light sources do not indicate any characteristics for minimizing low angle back scatter better than white light.

Light sensing through a light polarizing filter does not change the scattering intensity pattern from dust at low back scatter angles.

One experimental variable produced a trend change in the phototube output making a hysteresis of angular scatter intensity for increasing angle tests followed by decreasing angle tests. This variable was caused by fatigue characteristics of the phototube and light source filament.

The largest size dust particles produce the most variable angular scatter pattern. The 14° and other low-angle back scatter minima of this experiment is a characteristic of the large dust particles. Results of this experiment support theoretical indications that an aerosol of large dust particles, assumed to absorb light, scatters light with more variation of angular scattering pattern than do small non-absorbing particles.

Largest particle sizes of this experiment forward scatter less light intensity than do smaller ones which agrees with previous experimenters. These largest particles, near 100 microns in size, absorb light.

A large proportion of different size dust particles limits minimizing scatter intensity at low back scatter angles.

D. Suggestions for Future Study

Since this experiment was an attempt at examining many conditions to find minimum light back scatter angles on field dust, more experiments are needed. First, field dust needs to be much better characterized by sampling it in normal field environment rather than desert condition. This could be done by sampling at different heights with a boom by vacuum as was applied by Chepil (45) to dust suspended by wind erosion or sampling by filter as did Engebretson (46). A characterization of this dust will then allow study of the field dust cloud theoretically or by air tunnel as did Zingg (47) for dust storms. The characteristics of field dust will allow making a smaple of it for scatter tests by a precise sizing method as an air elutriator.

Using the field dust, a more extensive angular light scatter test should be made with a better designed source of a dust cloud in which the concentration can be varied down to that in which primary particle scattering is assured. The angular light scatter intensity should be sensed by recording instruments to find all variations with scatter, not just definite angles.

For accurately finding contribution of the sizes of particles, air elutriator samples can be used to test monodisperse particle scattering. This should particularly be tested in the larger particle size ranges, from which the largest amount of back scatter is expected. Also, typical polydisperse samples of field dust should be used to determine whether the scatter is consistent enough that a non-varying angular scatter minimum is observed. Possibly, the polydisperse nature of dust and fog in nature is the factor that has kept scatter minimization from being affected in practice.

Other experiments should test more exact frequency ranges in the presence of polarized light to determine its effect. A nephelometer should be devised which would measure angles to a limit at least as low as one degree back scatter.

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APPENDIX

Tests on all back scatter angles with white light on no dust cloud produced no phototube return voltage above background noise voltage level.

Legend: ϕ = Back Scatter Angle in Degrees, v = Background Noise Volts.
V = Phototube Return Volts.

All background noise voltages not entered are same as last one in column.

SIZED DUST 105 TO 74 MICRONS FOR WHITE LIGHT

ϕ	Test 1		Test 2		Test 3		Test 4	
	v	V	v	V	v	V	v	V
5					.144	.580		
6					.143	.560		
7					.143	.520		
8						.520	.138	.500
9						.505		.520
9.5						.465		.520
10						.470		.500
10.5						.465		.500
11						.480		.500
11.5								.505
12						.475		.485
12.5	.19	6.80	.16	6.25				
13	.16	6.70		6.25		.444		.480
		6.85						
		6.85						
		6.60						
14		6.20		5.85		.422		.465
14.5		6.25						
15		6.05		5.80	.138	.402		.460
16		5.80		5.60				
17		5.85		5.40				
18		5.45		5.30				
19		5.45		5.30				
20		5.60		5.10				
25		4.80		4.85				
30		4.20		4.55				
45		3.40		3.55				
60		2.85		2.85				

SIZED DUST 74 TO 53 MICRONS FOR WHITE LIGHT

ϕ	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V
5					.140	.610	.141	.645
6					.142	.705		.645
						.685		
7					.142	.625		.640
8					.142	.615		.630
9					.143	.565		.620
						.575		
10					.140	.525		.560
						.540		
11					.141	.525		.550
12						.525		.550
12.5	.14	5.6	.14	5.35				
13		5.5		5.2		.505		.525
13.5		5.35		5.2				
14		5.25		4.95		.505		.505
14.5		5.2		5.0				
15		5.05		4.95				
15.5		5.2		5.0				
16		5.25		5.05				
16.5				4.9				
17		4.95		4.8				
18		5.00		5.00				
19		4.60		4.65				
20		4.35		4.60				
21		4.35		4.60				
22		4.30		4.30				
23		4.25		4.45				
24		4.20		4.30				
25		3.90		4.20				
30		3.70		3.65				
45		3.05		2.80				
60		2.50		2.40				

SIZED DUST 53 MICRONS AND SMALLER FOR WHITE LIGHT

ϕ	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V
5					.142	.645		
6					.142	.645		
7					.142	.635		
8					.140	.615		
9					.140	.575		
10						.550	.140	.550
10.5							.141	.520

CONTINUED SIZED DUST 53 MICRONS AND SMALLER FOR WHITE LIGHT

∅	Test 1		Test 2		Test 3		Test 4	
	v	V	v	V	v	V	v	V
11					.140	.500	.142	.515
11.5								.520
								.480
12						.500		.500
12.5	.17	6.3	.20	6.2		.505		
		6.3		5.85				
13	.18	6.1		6.2				
				6.05				
13.5				5.95				
				6.05				
14	.14	5.9		6.0				
14.5	.13	5.9		5.9				
15	.13	5.9		5.8				
16	.15	5.7		5.65				
17	.22	5.75		5.5				
18	.22	5.3		5.35				
19	.22	5.2		5.15				
20	.22	5.25		4.85				
25	.22	4.65		4.5				
30	.20	4.45		4.05				
45	.20	3.2		3.2				
60	.20	2.65		2.65				

WHITE LIGHT ON POLYDISPERSE DUST

∅	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	v	V	v	V	v	V	v	V	v	V	v	V
5					.5	2.37						
					.5	2.37						
6						2.38						
7						2.40						
8						2.31						
						2.31						
9						2.17						
						2.10						
10						2.01						
						2.01						
11						1.82						
12						1.61						
12.5				5.35			.25	4.4	.27	4.55	.2	4.5
								4.3		4.55		
								4.5				

CONTINUED WHITE LIGHT ON POLYDISPERSE DUST

ϕ	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	v	V	v	V	v	V	v	V	v	V	v	V
13	.30	4.27	.31	*4.7	.5	1.82	.25	4.35	.27	4.30	.24	4.55
								4.25		4.35		
								4.25				
								4.30				
13.5				5.4					.27	4.15	.25	4.40
			.32	*4.5						4.20		
				*4.5								
14	.30	4.25		5.25	.5	1.65	.32	4.05	.27	4.10	.25	4.20
			.33	*4.6		1.70		4.3		4.05		
								4.2		4.10		
								4.15		4.10		
14.5				5.25						4.35		4.30
										4.25		
15	.31	4.45		5.25		1.70	.27	4.20		4.35		4.55
						1.72		4.15		4.30		
16	.29					1.72	.27	4.0		4.25		4.4
								4.0		4.20		
17	.29	4.35					.27	4.0		4.30		
								4.25		4.30		
18	.30	4.05					.28	4.4		4.25		
								4.5		4.05		
19	.32	4.15					.28	4.55		4.15		
								4.6		4.15		
20	.30	4.20					.29	4.5		4.05		5.1
										4.2		
21	.30	4.15					.26	4.3		3.95		
										3.95		
22	.33	4.20					.26	4.35		3.85		
										4.05		
23	.33	4.35					.27	3.95		4.10		
								4.00		3.80		
24	.32	4.35					.27	4.10		4.00		
		4.35						4.35		3.95		
								4.20				
25	.32	3.95						3.85		3.90		4.45
		4.00										
26	.30	3.90										
27	.33	4.00										
		3.90										
28	.33	3.70										
29	.37	3.80										
		3.70										
30	.39	3.80						4.0		3.65		4.4
								3.9		3.65		
31	.37	3.75										
32	.34	3.75										
33	.34	3.65										

CONTINUED WHITE LIGHT ON POLYDISPERSE DUST

ϕ	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	v	V	v	V	v	V	v	V	v	V	v	V
34	.33	3.5										
35	.35	3.45									.25	4.05
36	.40	3.2										
		3.3										
37	.40	3.5										
38	.39	3.4										
39	.40	3.3										
40	.33	3.45										3.85
41	.39	3.25										
42	.39	3.1										
		3.0										
43	.39	3.1										
44	.32	3.25										
		2.95										
45	.38	3.0					.27	2.9	.27	2.9		3.4
								2.9				
46	.39	2.85										
47	.39	2.8										
48	.39	2.9										
49	.37	2.85										
50	.39	2.9										3.25
51	.39	2.8										
52	.36	2.7										
53	.37	2.8										
54	.39	3.0										
		2.8										
55	.38	2.75										3.2
56	.39	2.75										
57	.39	2.75										
58	.38	2.65										
59	.37	2.7										
60	.38	2.6						2.3		2.3		3.05
61	.30	2.8										
62	.39	2.7										
63	.36	2.7										
64	.37	2.75										
65	.34	2.75										2.9
66	.31	2.7										
		2.75										
67	.30	2.7										
		2.8										
68	.28	2.7										
		2.8										
69	.25	2.9										
		2.9										
70	.20	2.75										2.75
75												2.6

CONTINUED WHITE LIGHT ON POLYDISPERSE DUST

∅	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V	Test 5 v	Test 5 V	Test 6 v	Test 6 V
100											.25	2.1
105												2.1
110												2.0
115												2.1
120												2.1
125												2.0
130												2.2
135												2.3
140												2.6
145												2.9
150												3.1
155												3.4
160												4.0
165												5.4
												5.4
170												6.8
												7.0
												7.0
171.5												8.2
												10.0

RED LIGHT ON POLYDISPERSE DUST

∅	Test 1 v	Test 1 V	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V	Test 5 v	Test 5 V
			v = 3.78						
5			.16						
			.16						
6			.20						
7			.22						
8			.22						
9			.20						
10			.20						
11			.16						
12			.16						
12.5	.138	.70				.155	.505	.160	.460
		.72					.525		.440
		.71					.505		.440
							.495		
13			.18	.143	.54	.159	.475	.160	.435
			.18				.465		.425
							.465		.430

CONTINUED RED LIGHT ON POLYDISPERSE DUST

ø	Test 1 v	Test 1 V	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V	Test 5 v	Test 5 V
13.5						.159	.465		
							.465		
14			.20	.141	.51	.159	.470	.160	.460
							.480		.460
							.465		
15	.155	.65	.19	.152	.51	.159	.505	.160	.420
		.67					.480		.430
							.470		
15.5						.160	.456		
16			.14	.155	.50		.455	.160	.420
17				.145	.48		.445	.160	.425
					.48				
18				.140	.47		.440	.150	.400
19				.141	.48		.435	.151	.420
20	.14	.63		.143	.46		.420	.160	.420
		.68							
		.67							
21				.142	.48		.420	.160	.435
22				.144	.48		.420		.420
23				.140	.47		.400		.385
24				.140	.48		.370		.370
25	.14	.52		.140	.46		.375		.375
		.52							
30	.14	.50					.355	.150	.350
		.48							
35		.43							
40		.41							
		.41							
45		.37					.280	.160	.270
		.36							.270
50		.37							
		.37							
55		.34							
60		.30					.240	.160	.230
70		.27							

YELLOW LIGHT ON POLYDISPERSE DUST

ø	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V	Test 5 v	Test 5 V	Test 6 v	Test 6 V
5			1.0	1.63								
6			1.0	1.95								
				1.90								

CONTINUED YELLOW LIGHT ON POLYDISPERSE DUST

∅	Test 1		Test 2		Test 3		Test 4		Test 5		Test 6	
	v	V	v	V	v	V	v	V	v	V	v	V
7			1.0	1.78								
				1.78								
8				1.71								
9				1.63								
10				1.59								
				1.59								
11				1.51								
12				1.48								
12.5	.30	1.65			.116	1.38	.137	1.045	.14	1.33	.20	1.80
						1.43		1.04				
						1.415						
13	.30	1.65		1.43	.125	1.395	.137	1.04	.14	1.30		
		1.65				1.385						
13.5					.119	1.27	.137	1.015		1.29		
						1.27		1.02				
14		1.5		1.39	.118	1.275		1.045		1.285		
				1.42		1.32		1.01				
14.5					.118	1.27		1.40		1.22		
						1.265		1.25		1.22		
15		1.6		1.43	.120	1.24		1.05		1.235		
				1.45		1.21		1.05				
						1.22						
15.5										1.215		
16		1.55		1.50	.120	1.18	.124	0.99		1.18		
				1.46		1.18	.124	0.98				
						1.20						
17		1.5			.121	1.17		0.965				
						1.175		0.975				
18		1.5			.124	1.16		0.960				
								0.940				
								0.940				
								0.940				
								0.940				
19		1.45			.126	1.155		0.95				
								0.935				
								0.930				
20	.128	1.37			.121	1.105		0.965				
		1.42				1.13		0.980				
21	.128	1.39			.121	1.065		0.900				
						1.065		0.900				
								0.900				
								0.900				
								0.935				
22		1.36			.124	1.09		0.955				
						1.09						
23		1.37			.124	0.99		0.940				
						1.01						

CONTINUED YELLOW LIGHT ON POLYDISPERSE DUST

ϕ	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V	Test 5 v	Test 5 V	Test 6 v	Test 6 V
24	.128	1.40			.124	.955	.124	.920				
						.97						
25	.130	1.38				.97		.900			.2	1.45
						.945						
						.945						
26	.126	1.32				.950		.870				
						.935		.890				
								.890				
27	.126	1.30										
27.5						.920						
28	.126	1.26										
29	.124	1.30										
30	.120	1.24				.860		.845				
31	.120	1.25										
32	.120	1.24										
34	.127	1.23										
36	.126	1.20										
38	.126	1.20										
40	.124	1.28										
43	.140	1.20										
		1.22										
44	.140	1.21										
		1.21										
45	.134	1.22				.660		.705				
								.705				
50	.143	1.15										
52.5	.140	1.13										
55	.140	1.07										
56	.140	1.08										
58	.142	1.06										
60	.138	1.03				.585		.585				
		1.03										
62.5	.144	1.03										
65	.140	.94										
		.98										
67.5	.127	.92										
70	.140	.86										

GREEN LIGHT ON POLYDISPERSE DUST

ϕ	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V
5			3.78	.09				
6				.18				

CONTINUED GREEN LIGHT ON POLYDISPERSE DUST

ø	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V
7			3.78	.14				
8				.14				
9				.14				
10				.14				
11				.12				
12				.12				
12.5	*.14	*.33			.136	.280	.130	.265
13	.144	.26		.15	.136	.265	.130	.265
						.265		.265
13.5					.136	.280		
14	.144	.26		.15	.138	.265	.128	.260
14.5					.138	.280		
15	.157	.26		.12	.138	.265	.128	.260
15.5					.138	.265		
16	.137	.26		.08	.138	.265	.128	.260
16.5					.138	.265		
17	.14	.24			.138	.265	.135	.260
18	.14	.24			.139	.242	.137	.245
19	.14	.22			.132	.230	.137	.240
		.23						
20	.142	.24			.136	.240	.135	.225
21	.146	.26			.140	.230	.128	.22
22	.140	.24			.140	.235	.128	.22
23	.140	.24				.220	.128	.22
24		.24				.215	.133	.22
25		*.24				.205	.133	.22
30					.136	.200	.128	.195
45					.135	.165	.129	.170
60					.133	.160	.126	.160

BLUE LIGHT ON POLYDISPERSE DUST

ø	Test 1 v	Test 1 V	Test 2 v	Test 2 V	Test 3 v	Test 3 V	Test 4 v	Test 4 V
5			3.78	.11				
6				.18				
7				.14				
				.14				
8				.13				
9				.13				
10				.11				
				.11				
11				.11				
12				.10				

CONTINUED BLUE LIGHT ON POLYDISPERSE DUST

ø	Test 1		Test 2		Test 3		Test 4	
	v	V	v	V	v	V	v	V
12.5	*.14	*.34			.14	.325	.14	.265
		*.34				.325		.270
13	.142	.27	3.78	.13		.32		.280
13.5						.32		
14	.143	.25		.12		.325		.280
14.5						.315		.275
15	.157	.26		.14		.315		.275
								.265
15.5						.305		.275
16	.138	.22		.10		.285		.265
		.25						.275
16.5						.280		.265
17	.140	.24				.285		.265
								.280
								.275
17.5						.295		.285
18	.140	.24				.285		.280
19	.140	.23				.275		.260
20	.143	.24				.275		.260
								.255
21	.144	.24				.265		.265
22	.140	.23				.245		.260
23	.140	.22				.245		.245
24	.140	.24				.240		.250
25	*.14	*.25				.230		.240
		*.25						
	.140	.23						
30						.220		.230
45						.195		.195
60						.165		.165

VIOLET LIGHT ON POLYDISPERSE DUST

ø	Test 1		Test 2		Test 3		Test 4	
	v	V	v	V	v	V	v	V
5			3.78	.13				
6				.18				
7				.16				
8				.15				
9				.13				
10				.11				
11				.09				
12				.08				
				.09				

CONTINUED VIOLET LIGHT ON POLYDISPERSE DUST

ϕ	Test 1		Test 2		Test 3		Test 4	
	v	V	v	V	v	V	v	V
12.5					.14	.275	.148	.240
						.275		.235
13	.14	.27	3.78	.08		.290	.148	.255
						.285		.250
14	.141	.28		.09		.275	.150	.245
				.09		.265		
						.265		
15	.147	.27		.11		.255	.150	.245
16	.144	.28		.10		.245	.150	.245
17	.148	.28				.245	.140	.225
18	.136	.25				.235	.142	.225
								.225
19	.137	.25				.235	.150	.230
20	.143	.255				.235	.150	.225
21	.140	.25				.230	.150	.220
22	.150	.26				.225	.150	.220
23	.142	.26				.220	.150	.220
24	.140	.26				.220	.150	.215
25	.140	.25			.145	.215	.150	.210
30					.143	.205	.146	.205
45					.160	.180	.144	.180
60					.160	.160	.160	.160

EFFECT OF POLARIZED FILTER ON WHITE LIGHT AND OTHER COLORS

ϕ	Color	Change Detected
15	White	No change at any orientation.
15	Red	No change as above.
15	Blue	No change as above.
30	White	No change as above.
45	White	No change as above.
		Below Polaroid at 55° orientation.
60	White	v = 0.09 V = 0.89
60	White	v = 0.102 V = 0.96
60	White	v = 0.102 V = 0.94

POLYDISPERSE DUST FALLOUT FOR WHITE LIGHT, BACK SCATTER ANGLE ϕ = 171.5°

Background Noise Voltage = 0.12. Lines are time in seconds from test. Data is return voltage in volts. Columns are each one of three tests.

	1	2	3
1		6	
2		8	8
3		10	
4		11	10
5		15	10
SHUTOFF OF DUST SUPPLY SIFTER			
6	14	15	22
7	15	6	12
8	8	7	15
9	9	5	21
10	15	4	19
11	14	5	17
12	15	4	16
13	12	7	13
14	11	8	11
15	9	15	9
16	6	15	10
17	7	15	8
18	6	15	7
19	4.5	15	6
20	5	15	5
21	3	15	3.4
22	2.5	15	2.0
23	2	15	1.7
24	1.5	12	1.7
25	1.5	9	1.0
26	1.5	9	1.0
27	1	10	1.0
28	1.5	11	1.1
29	1	8	1.1
30	1.5	6	1.2
31	1.5	6	1.2
32	1	6	1.7
33	1	5	1.6
34	1	6	1.9
35	0.6	5	1.8
36	0.7	5	1.7
37	0.6	5	1.65
38	0.6	5	1.65
39	0.4	4	1.8
40	0.3	3	1.8
41	0.3	3	0.8
42	0.4	3	0.65
43	0.3	3	0.54
44	0.4	3	0.65
45	0.4	3	0.55
46	0.4	2.5	0.4
47	0.4	2.5	0.4
48	0.4	2	0.35
49	0.4	1.5	0.3
50	0.4	1.5	0.3
51			0.3
52			0.3
53			0.4
54			0.4
55	0.3	0.8	0.4
56			0.5
57			0.6
58			0.7
59			0.7
60	0.3	0.8	0.6
61			0.5
62			0.5
63			0.5
64			0.5
65	0.4	0.6	0.5
66			0.4
67			0.4
68			0.5
69			0.4
70	0.4	0.6	0.35
71			0.4
72			0.4
73			0.35
74			0.35
75	0.4	0.5	0.4
76			0.45
77			0.35
78			0.4
79			0.55
80	0.4	0.5	0.6
81			0.65
82			0.65
83			0.6
84			0.55
85	0.4	0.5	0.55
86			0.45
87			0.45
88			0.35
89			0.4

CONTINUED POLYDISPERSE DUST FALLOUT FOR WHITE LIGHT, BACK SCATTER ANGLE ϕ = 171.5°.

	1	2	3	1	2	3
90	0.4	0.5	0.3			
91			0.25			
92			0.25			
93			0.2			
94			0.25			
95	0.5	0.5	0.2			
96			0.3			
97			0.3			
98			0.2			
99			0.25			
100	0.4	0.5	0.2			
105	0.4	0.5	0.2			
110	0.4	0.5	0.2			
115	0.4	0.5	0.17			
120	0.4	0.5	0.15			
125	0.2	0.4	0.14			
130		0.3	0.14			
135		0.25	0.14			
140		0.2				
145		0.2				
150		0.2				
155		0.18				
160		0.17				
165		0.17				
170		0.17				
175		0.17				
185		0.16				
195		0.16				
205		0.15				
215		0.14				
225		0.13				
235		0.12				
145		0.12				

VITA

Carl Vernon Hays

Candidate for the Degree of

Master of Science

Thesis: NEPHELOMETRIC DETERMINATION OF MINIMUM BACK SCATTER TO LIGHT FROM FIELD DUST

Major Field: Agricultural Engineering

Biographical:

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Professional experience: Associate Member, American Society of Agricultural Engineers, who made Student Honor Award, June, 1954; Engineer-In-Training, State Board of Registration for Professional Engineers; Member, Sigma Tau; sold article, "Are Your Tractor Lights Right?" printed in Capper's Farmer Magazine, May 1956; completed patent disclosure on "An Electrical Depth Control for Hydraulically Actuated Tractor Drawn Farm Machinery," reviewed by Office of Judge Advocate General and Government Patents Board; owner partner of Hays-Sutherland Research Laboratories engaged in invention development and electrical power service engineering designated outstanding by Yuma Supervisor, Arizona Public Service Company, 1958; recieved the Air Force Outstanding Unit Award for typhoon forecasting in the Far East; Staff Weather Officer, 7th Fighter-Bomber Wing, Tainan, Taiwan (Formosa); Commander, Det 1, 3d Weather Group and Staff Weather Officer, 4750th Air Defense Wing, Vincent Air Force Base, Arizona for which recieved commendation from Commander, 3d Weather Group, Colorado Springs, Colorado.