COMMONWEALTH OF AUSTRALIA
DEPARTMENT OF EXTERNAL AFFAIRS

AUSTRALIAN NATIONAL ANTARCTIC RESEARCH EXPEDITIONS

ANARE INTERIM REPORTS

SERIES A (IV) GLACIOLOGY

PUBLICATION No. 79

THE PHOTOELECTRIC METERING OF WIND-BLOWN SNOW

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A NEW PHOTOELECTRIC DRIFT SNOW GAUGE

by
E. R. WISHART

ISSUED BY THE ANTARCTIC DIVISION
DEPARTMENT OF EXTERNAL AFFAIRS, MELBOURNE
1965

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(Manuscript received March 1964)

ABSTRACT

Several designs of electronic drift snow gauges are described including one photoelectric type which has been calibrated against a Mellor snow trap under Antarctic conditions.

The theory of light attenuation by drifting snow is discussed and a theoretical calibration curve is derived which agrees well with the empirical results. The theory suggests an exponential relationship between the mass of drift snow per unit volume of air (drift density) and the output signal from the photoelectric gauge. However, for low drift densities (below 40 gm m^{-3}) commonly encountered at heights of 1 metre and more above the snow surface, this relationship is approximately linear. The problem of variation in snow particle size distribution and its effects on the calibration is also discussed.

Within limits set by the above considerations, photoelectric gauging of snow drift offers wide possibilities for drift measurements which have not so far been feasible.

CONTENTS

I. INTRODUCTION

The mass transport of snow by wind is a significant factor in the moisture and mass budgets of the Antarctic continent. To date, measurements of the mass of drift snow per unit volume of air (drift density) have been made exclusively by means of mechanical type collectors (cf. Barré, 1953; Lister, 1960; Mellor, 1960; Govorukha and Kirpichev, 1962; and Soviet I.G.Y. Reports, 1960).

The measurement of drift density using mechanical collectors is a laborious task necessitating frequent trips out into the blizzard by the operator who has to expose and collect the traps at frequent intervals for weighing. The difficulties involved have resulted in measurements of drift density being made only at established bases. Moreover, because of hazards involved, measurements have not been made at heights of more than a few metres above the ground.

Extensive measurements of drift density have been made at Mawson, Wilkes and Byrd stations using the collector designed by Mellor (1960) (cf. Mellor and Radok, 1960; Dingle and Radok, 1961; and Budd, Dingle, and Radok, 1965). Empirical data obtained were limited to the first 4 metres above the snow surface, and observations above this level would be particularly valuable.

Other investigators have estimated, from drift density measurements, the total annual mass transport of snow by wind across the edge of the Antarctic continent (cf. Loewe, 1956; Mellor, 1959; Kotlyakov, 1960; and Lorius, 1962). Such estimates are only approximations as it has not been possible to measure densities continuously during all periods of drift by means of mechanical collectors.

In order to develop an instrument, simple and versatile in operation and capable of overcoming the limitations of mechanical collectors, experiments have been made with types of electronic gauges.

The first tests with an electronic system, employing a series of photocells on a mast illuminated by an Aldis lamp, were undertaken by Lister (1960) at Southice. Lister encountered a number of problems with this system which rendered it unsatisfactory.

On the suggestion of Dr. U. Radok of the University of Melbourne, investigations into the electronic measurement of drift density were undertaken by the authors as members of the Australian National Antarctic Research Expeditions, 1962. Initially, two fundamentally different systems were investigated. The first of these employed the principle of beta ray attenuation but this quickly proved impracticable. In the second system, the attenuation of a modulated light beam was measured by a phototransistor. A gauge based on the second principle was tested at Mawson, Antarctica, during 1962 and proved fundamentally unsatisfactory. However, it provided the starting point for a third type of gauge employing a constant light source illuminating a photoconductor across a shallow rectangular tube exposed to the drift snow. This last system underwent a number of developments and finally became an operational gauge. It should be mentioned that a gauge remarkably similar in conception appears to have been developed by Orlov (1961).

In this paper the different designs of electronic drift gauges will be discussed in turn (Section II), special consideration being given to the operational version and its calibration results (Section III). For the proper interpretation of the results, theoretical aspects of photoelectric drift metering must be considered in some detail (section IV); some difficulties arising from theoretical considerations and ways of overcoming them are indicated (Section V). Finally, an improved design of drift gauge is discussed (Section VI).

II. TECHNICAL DETAILS OF ELECTRONIC DRIFT GAUGES

(*a*) *β ray attenuation*

Beta rays initially appeared to offer a straightforward method for the measurement of drift density, since the attenuation of a beta ray beam by a medium through which it passes is proportional to the density of the medium. A simple theoretical consideration, however, shows that fluctuations in the amount of drift snow in the air will have an effect on beta rays which is of the same order of magnitude as that produced by air density fluctuations due to temperature changes and wind gusts.

Available information on drift snow concentrations (cf. e.g. Budd, Dingle and Radok, 1965) suggests the following typical values for different levels in a 30 m sec^{-1} wind:

Height above surface (cm)	Drift density (gms m^{-3})
3	300
10	100
100	10

An operational drift gauge would be particularly useful at high levels where it would be required to measure concentrations as low as 0·1 gm m^{-3}. This represents approximately 0·08% of the standard air density of 1293 gms m^{-3} at 1000 mb and 0°C, and a comparable change in the air density would be produced by an isobaric temperature change of merely 0·2°C or an isothermal pressure change of 0·8 mb. Hence an instrument employing beta rays would respond to air temperature and pressure fluctuations rather than changes in drift density.

(*b*) *A photoelectric gauge using modulated light*

The attenuation of a beam of light offered another means of metering drift density, and a photoelectric device was constructed to specifications supplied by Dr. Radok. It consisted of a modulated light source (50 cycles sec^{-1}) illuminating two phototransistor detecting heads. One head, for measuring purposes, was illuminated through the drift snow, and the other, for reference purposes, was illuminated through snow free air. Each phototransistor head had an inbuilt AC discriminating amplifier, and the output from either one could be selected to be fed through a rectifier and a DC amplifier, to a milliamp meter.

Two major difficulties were encountered when this device was used in Antarctica. Firstly, the phototransistors proved to be extremely temperature-sensitive although a cold-room test in Melbourne had given no indication of this. The normal ambient temperatures at Mawson, —30° to —10°C, in fact represent a range in which phototransistors cannot as a rule operate satisfactorily. Secondly, a difficulty arose from fluctuations in the ambient light associated with pulses of snow drift: under such conditions a frequency-discriminating photo-detector is no longer insensitive to ambient light thus making it impossible to identify genuine fluctuations in drift density.

While the phototransistor arrangement therefore proved useless, it suggested a new approach which in due course led to the development of the operational drift gauge described in Section II (*c*).

(*c*) *A photoelectric gauge employing photoconductors*

With the experience of the phototransistor arrangement the authors developed a new system with a cadmium sulphide photoconductor of type Philips B 873103. While reasonably temperature insensitive this device has too long a response time to permit the use of modulated light. For this reason a stabilized light source was used and both light source and sensor were placed in a rectangular tube exposed to the drift and painted mat black inside to exclude the ambient light. The entire device was pivoted to enable it to weathercock and thus orientate the axis of the tube into the direction of the wind (cf. Plate 1).

In initial tests the photoconductor was connected in series with a simple linear circuit. A potential was supplied across the photoconductor by means of a potential divider and a 6V cell, and a mA meter measured the current flow. This circuit was the essence of simplicity; however, drift densities to the order of 200 gm m^{-3} were necessary to produce a half scale deflection on the meter. As it was desired to detect drift densities as low as 0·1 gm m^{-3}, considerable amplification was required, and an amplifier was designed and built for the purpose.

The final prototype gauge consisted of a 30W lamp, driven by a constant voltage supply from a 12 V wet cell accumulator, illuminating the

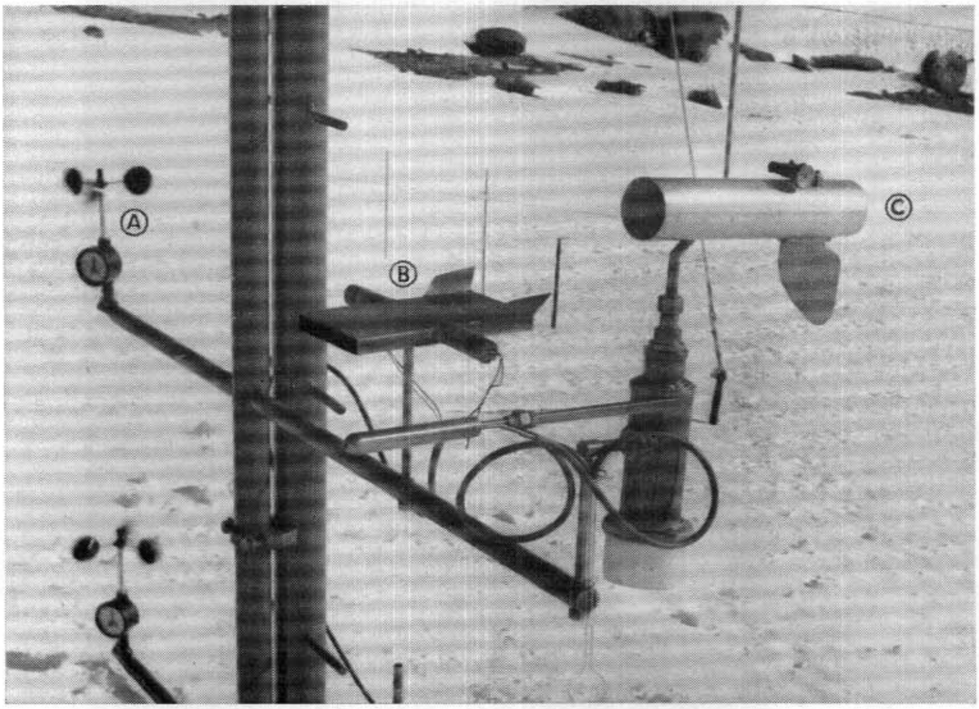

PLATE 1. The photoelectric drift gauge head (B) exposed together with an anemometer (A) and a mechanical drift trap (C). Note that the mechanical drift trap shown is not the type that was used for calibration.

photoconductor. The photoconductor was connected into a bridge circuit as illustrated in Figure 1. Output from the amplifier was recorded on a 1 mA movement pen recorder. Several different time constants, ranging from 4 sec to 45 sec, could be introduced into the circuit using electrolytic capacitors, and three different ranges of amplification could be selected depending upon the density of drift being measured.

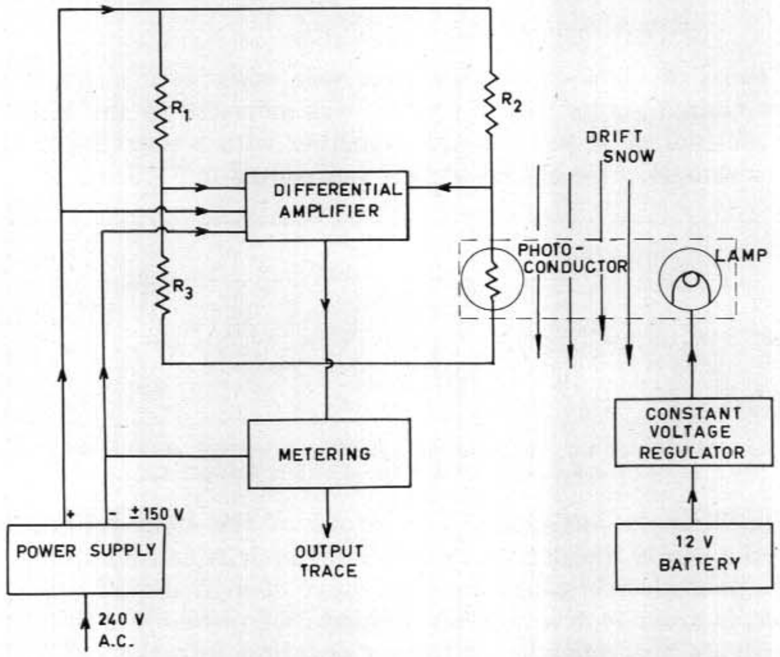

FIG. 1. Block diagram of photoelectric drift gauge circuit.

Ambient light effects were minimised by using a high intensity of illumination from the 30 W globe. Illumination intensity on the photoconductor surface was to the order of 250 lux.

III. OPERATION AND CALIBRATION OF THE PHOTOCONDUCTOR GAUGE

(a) *Operation*

In order to calibrate the photoconductor gauge it was exposed to drift together with an anemometer and a rocket type drift snow collector of the type described by Mellor (1960). The required amplification range was next selected to suit the drift conditions. The light source was then adjusted to give zero output signal in air free of drift snow. To achieve this condition the ends of the rectangular tube were blocked and the light level was regulated to give the desired zero amplifier output. After that, drift density measurements could be made.

Changes in light intensity during a run presented a difficult problem which could be overcome only by frequent checks and adjustments of the light level. The gauge was so sensitive to small light fluctuations that even vibrations of the lamp filament could be detected in the output trace recorded with a small time constant. The output traces were averaged over periods of the order of 30 minutes and these averages were collated with the drift densities obtained from the snow catches in the Mellor trap.

(*b*) *Calibration*

A series of eight calibration runs was made over a range of drift densities from 3 gm m^{-3} to 15 gm m^{-3} (as indicated by the Mellor trap). A time constant of 45 sec was used, together with a chart speed of 6 inch $hour^{-1}$; a sample of the output trace is reproduced in Figure 2.

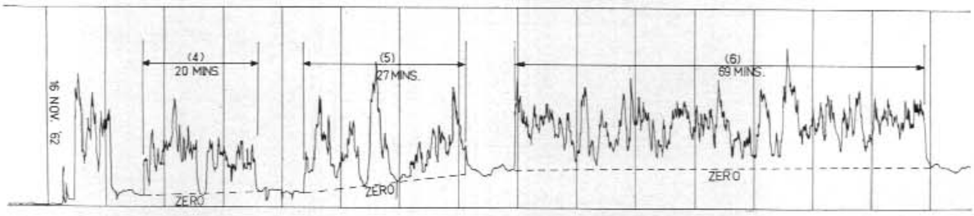

FIG. 2. An example of the amplifier output trace recorded with a time constant of 45 seconds, and a chart speed of 6 inches per hour.

A preliminary analysis of the results of the eight calibration runs suggested a nearly linear relationship between drift density and the output from the photoelectric gauge over the range of drift densities in question. However, in order to fit a calibration line to the results it is first necessary to investigate theoretically all factors entering into the calibration, especially the attenuation of a beam of light by drift particles.

IV. THEORETICAL ANALYSIS OF THE RELATIONSHIP BETWEEN DRIFT DENSITY AND PHOTOELECTRIC GAUGE OUTPUT

(*a*) *Preliminary considerations*

The output signal M of the photoelectric drift gauge will vary as some function of the drift density D:

$$M = f(D) \tag{1}$$

The form of this equation will depend on the following relationships:

(i) Drift density versus projected areas of particles.
(ii) Projected areas of particles versus the attenuation of the light beam.
(iii) Intensity of the light beam incident on the photoconductor versus the resistance of the photoconductor.
(iv) The resistance of the photoconductor versus the amplifier output (i.e. amplifier circuit gain).

For the purpose of the present discussion the distribution of effective diameters of drift particles is assumed constant; the drift density will therefore depend only on the number of particles in a unit volume of air. This disposes of relationship (i). The relationship (iii) has been investigated and has been found linear. The relationship (iv) is also linear. It can be seen therefore that the function (1) depends mainly upon the relationship (ii) between the projected drift particle areas and the attenuation of the light beam. This can now be determined theoretically.

(*b*) *The attenuation of a light beam by drift particles*

A detailed study of the shape and size distribution of drift particles has been made by Budd (1965) as part of the Byrd Drift Project (Budd, Dingle and Radok, 1965). The results of this study show that drift particles are roughly spherical in shape having a mean shape factor (greater diameter/smaller diameter) of approximately 1·5. Drifting particles are obviously random in orientation and, by virtue of their physical characteristics, they can be considered as isotropic scatterers of light. The measurements show that the smallest particles have minimum diameters to the order of 30λ, where λ is the wavelength of the light to which the photoconductor is sensitive (around 0·6 microns). The problem therefore is the fundamental one of light attenuation by particles which scatter isotropically, and which are large compared with the wavelength of light. This problem has been discussed, for example, by Lothian and Chappel (1951) and van de Hulst (1958). The fractional reduction in the intensity of a parallel beam over the length dl, by particles of mean cross-sectional area $\bar{a}$ can be written in the form:

$$\frac{dI}{I} = -K\, n\, \bar{a}\, dl \qquad (2)$$

where I is the intensity of light at dl, n is the number of particles per unit volume, and K is the total scattering coefficient.

The value of K will depend upon the following factors:

(i) The intensity of light diffracted at the edges of the particle and lost from the solid angle subtended by the detector at the particle θ_d (cf. Figure 3).

(ii) The intensity of light incident on the particle which is scattered forward into the solid angle θ_d.

The total intensity of light *diffracted* at the edges of a single particle is equal to that incident on the particle. Thus, for the hypothetical case in which θ_d is zero, the amount of light lost from the beam due to diffraction will be equal to the amount of light incident on the particle and scattered from the beam, and therefore the value of K will be 2. As θ_d is increased to small values an increasing amount of diffracted light will be included in θ_d and the value of K will rapidly approach 1. The fraction of the amount of light incident on the particle which is *scattered* forward into θ_d will of course be $\theta_d/4\pi$. As θ_d increases to large angles the value of K will therefore decrease below 1.

The geometry of the drift gauge (cf. Figure 3) is such that θ_d must lie approximately between 6×10^{-3} steradians (for particles as close as possible to the photoconductor) and 1×10^{-3} steradians (for particles as close as possible to the light source). Hence for a particle in any position in the beam, both the amount of incident light scattered into θ_d, and the amount of diffracted light lost from θ_d only amount to a very small percentage of the total light incident on the particle, and thus the value of K in the case of the drift gauge will be always close to 1.

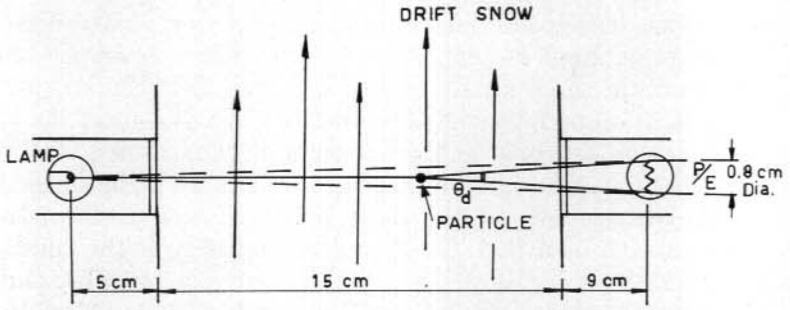

FIG. 3. Geometry of the photoelectric drift gauge head.

Equation (2) can be reduced to:

$$\frac{dI}{I} = -\frac{\pi}{4}\,\overline{x^2}\,n\,dl \tag{3}$$

where $\overline{x^2}$ is the mean square particle diameter. From the assumption already made that the drift particle size distribution is constant it follows that $\overline{x^2}$ is constant and therefore equation (3) can be written as:

$$\frac{dI}{I} = -\,k\,D\,dl \tag{4}$$

where k is a coefficient, dependent on the particle size distribution, and given by:

$$k = \frac{\pi\,\overline{x^2}\,n}{4\,D} \tag{5}$$

Integration of equation (5) over a beam length L gives:

$$I_L = I_o\,e^{-kDL} \tag{6}$$

where I_o is the initial intensity of the beam.

(*c*) *Theoretical calibration*

It is obvious that equation (6) also holds for the case of a beam diverging from a point source as in the case of the drift gauge. L becomes the distance between the light source and the photoconductor and I_o is the initial intensity of the light beam in the solid angle subtended by the photoconductor at the light source. The theoretical output M of the drift gauge is actually a measure of

$$M = \frac{I_o - I_L}{I_o} = 1 - e^{-kDL} \tag{7}$$

Expanding equation (7) gives:

$$M = k\,D\,L - \frac{(k\,D\,L)^2}{2!} + \frac{(k\,D\,L)^3}{3!} \tag{8}$$

The coefficient k from (5) can be written as:

$$k = \frac{\pi\,\overline{x^2}\,n}{4\,D} = \frac{1{\cdot}5\,\overline{x^2}}{\rho\,\overline{x^3}} \tag{9}$$

where $\overline{x^3}$ is the mean cubed drift particle diameter and ρ is the density of ice.

A numerical value for k can be determined from the statistics of drift particle sizes investigated by Budd (1965). Budd showed from the gamma distribution of drift particle diameters that $\overline{x^2}$ and $\overline{x^3}$ are given by:

$$\overline{x^2} = (\bar{x})^2\left(1 + \frac{1}{\alpha}\right) \tag{10}$$

$$\overline{x^3} = (\bar{x})^3\left(1 + \frac{3}{\alpha} + \frac{2}{\alpha^2}\right) \tag{11}$$

where α^{-1} is the square of the coefficient of variation of the gamma distribution. For the Byrd particles α had a numerical value of approximately 15.

Using as a mean diameter $\bar{x}$, the value 0·1 mm we obtain from (9) $k = 1{\cdot}46 \times 10^{-2}\ \mathrm{m^2\,gm^{-1}}$. From this value of k, and the length of the light path L equal to 20 cm, equation (8) can be written

$$M = 2{\cdot}92\,D - 4{\cdot}26\,D^2 \times 10^{-3} + 4{\cdot}15\,D^3 \times 10^{-6} \tag{12}$$

This equation (12) represents a theoretical calibration curve for the photoelectric drift gauge. As the units M are arbitrary, a factor of 10^{-3} has been removed from equation (12).

In the derivation of equation (12) multiple scattering has been neglected. However, van de Hulst (1957) has discussed the significance of multiple scattering giving the following simple criterion to investigate its effect on attenuation. If the value of $kDL < 0{\cdot}1$ then multiple scattering can be neglected, if $0{\cdot}1 < kDL < 0{\cdot}3$ then some correction may be necessary, and finally if $0{\cdot}3 < kDL$ the problem of attenuation involves the full complexities of multiple scattering. For the drift gauge, therefore, the theoretical calibration equation will hold for drift densities up to 34 gm $\mathrm{m^{-3}}$ and for drift densities above this value it will become increasingly approximate.

Equation (12) has been plotted in Figure 4 together with the linear function given by:

$$M = 2{\cdot}92\,D \tag{13}$$

A double log co-ordinate system has been used in order to illustrate the variation of equation (12) from the linear function over a wide range of drift densities.

(*d*) *Comparison between theoretical and empirical calibrations*

The empirical calibration of the drift gauge was made over a range of drift densities between 3 and 15 gm m^{-3}. It can be seen from Figure 4 that over this range the theoretical curve given by equation (12) is extremely close to the linear function given by equation (13). It is permissible, therefore, to fit a linear regression to the empirical results. In order that the mean of these results should coincide with the theoretical line, the values of the dependent variable M were multiplied by an arbitrary scale factor. The regression line of the results then has the form:

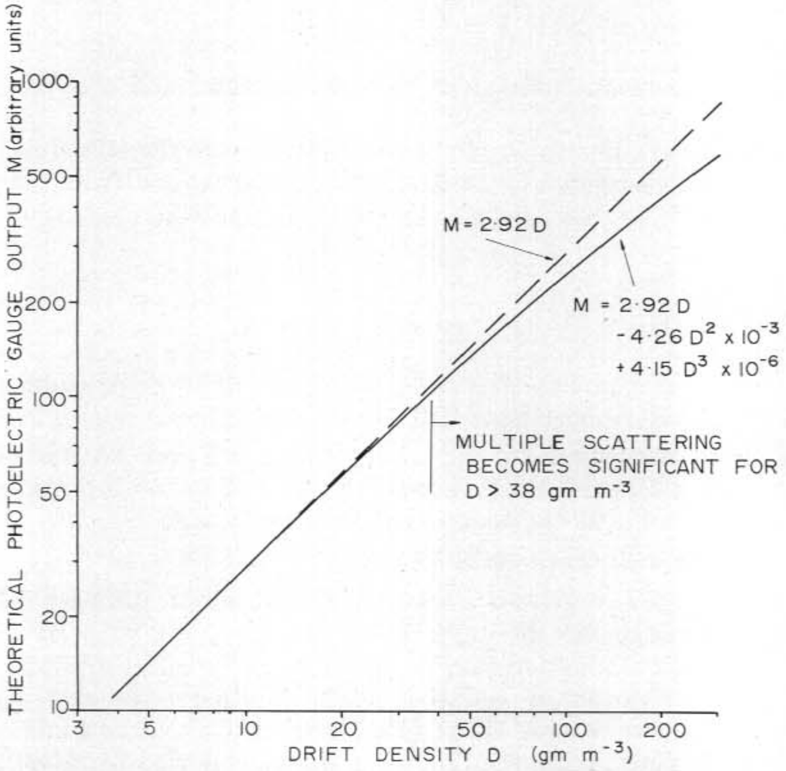

FIG. 4. Theoretical calibration line for the photoelectric drift gauge.

$$M = 2{\cdot}51\,D + 3{\cdot}6 \tag{14}$$

This regression line is plotted together with the theoretical line given by equation (13) in Figure 5.

It remains to test whether the difference between the two lines is significant or whether it can be ascribed to sampling. Student's t computed from the difference of the two slopes is 1·69. This gives a probability of 15% for a line to have a deviation from the theoretical line greater than that of the empirical line. Therefore, there is no significant difference between the theoretical and empirical calibrations.

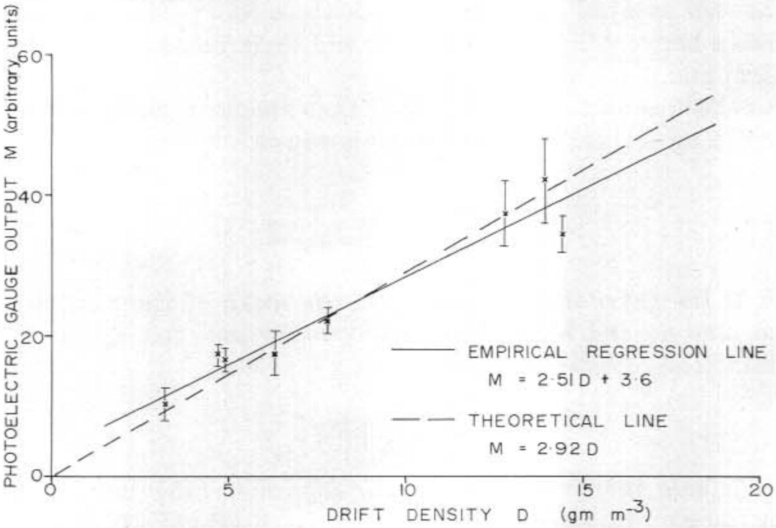

FIG. 5. Empirical calibration line for the photoelectric drift gauge. Measurements of D were made with a Mellor-type collector. Error bars give an estimation of errors arising from drift in the zero setting during a calibration run.

V. PROBLEMS IN PHOTOELECTRIC DRIFT GAUGING ARISING FROM THEORETICAL CONSIDERATIONS

From the theoretical considerations three problems are envisaged in the photoelectric gauging of drift snow. These will be discussed in turn.

(*a*) *Averaging the output signal at high drift densities*

Drift density varies continually with time, and unless the function relating drift density to gauge output is linear, or nearly so, then the output values cannot be averaged simply to give a correct mean value of drift density over an interval of time. It can be seen from Figure 4 that the drift density to gauge output relationship is approximately linear for drift densities below 30 gm m^{-3}. This value represents the order of magnitude of the maximum drift density encountered at the 25 cm level (Budd, Dingle and Radok, 1965). Hence the generalization is permissible that the interpretation of the photoelectric drift measurements must become significantly more difficult when the instrument is used in heavy drift below the 25 cm level.

(*b*) *The effect of change in particle size distribution*

It was shown in Section IV(*c*) that the attenuation of a light beam by spherical particles of the sizes occurring in snow drift depends on the mean square and mean cubed particle diameters. These in turn are related to the mean diameter of the particles by virtue of their approximate gamma distribution. Since the particle size distribution depends on height as well as wind speed (Budd, 1965), it follows that in general, the relationship between light attenuation and drift density will change with both height and wind speed.

It has been shown by Budd (1965) that the mean particle diameters at an arbitrary level z, and some standard level z_1 are related by:

$$\bar{x}_z = \frac{\bar{x}_{z_1}}{1 + \frac{B}{Ku_*} \log \frac{z}{z_1}} \tag{15}$$

where B is the ratio of the variance to the mean of the particle size distribution, and u_* and K are the shear velocity and von Karman constant determining the vertical wind profile:

$$V_z = \left(\frac{u_*}{K}\right) \log \left(\frac{z}{z_o}\right) \tag{16}$$

where z_o equals the roughness length. Equation (15) was confirmed as valid for the particle size data obtained at Byrd (Budd, Dingle and Radok, 1965) and at Southice (Lister, 1960). Typical values of the mean particle diameter $\bar{x}$ at different heights for a 20 m sec^{-1} wind (measured at the 10 m level) are given in the following table (after Budd, 1965):

Height (cm)	Mean Particle Diameter x (microns)	Attenuation Coefficient k (m^2 gm^{-1})
10	110	$1{\cdot}32 \times 10^{-2}$
100	92	$1{\cdot}58 \times 10^{-2}$
1000	80	$1{\cdot}81 \times 10^{-2}$

It should be noted that u^* is proportional to the wind speed at any given height z. Equation (16) therefore implies that an increase in wind speed reduces the variation in the mean particle diameter with change in height.

Equations (9), (10), (11) and (16) make it possible to determine the coefficient k as a function of height and wind speed; hence for a given wind speed the light attenuation—drift density relationship applying at different levels can be predicted by using equation (8). This has been done for two wind speeds (12 and 20 m sec^{-1}) and the results are shown in

Figure 6 as "errors" or deviations from a calibration correct at the 10 cm level.

Figure 6 shows that the effect of mean particle size variation is substantial. The rate of this variation, however, decreases rapidly with height as well as with wind speed, and for a gauge calibrated and used above the 100 cm level the errors would remain within the expected accuracy of the optical drift gauge.

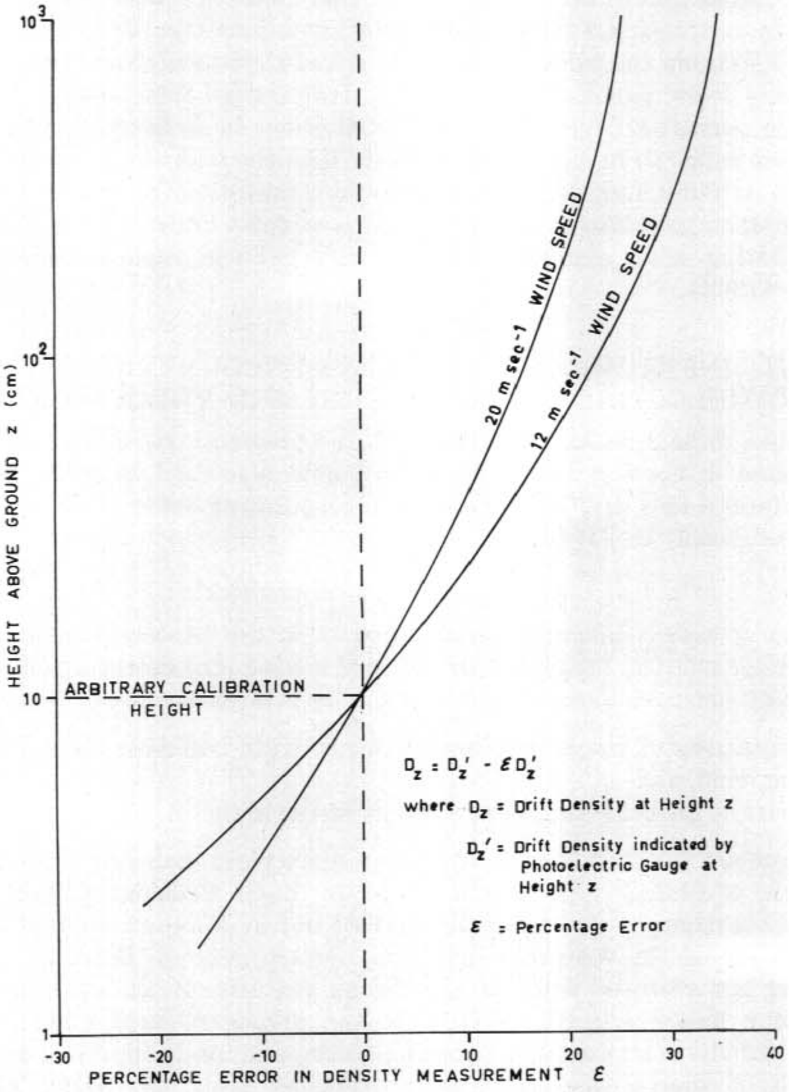

FIG. 6. Percentage errors in photoelectric drift gauge readings due to mean particle size variation with height and wind speed.

(*c*) *The effect of particle shape*

The entire discussion so far has assumed that the drift snow particles have approximately spherical shape. This is only partially true as discussed in Section IV (*a*). Moreover, snow drift is often accompanied by snow precipitation and new snow flakes have quite different characteristics as regards both shape and size from drift snow.

The particle size distributions of drifting and precipitating snow have been studied by Diunin (1955) who found them to differ considerably. Diunin found that at the snow surface mean diameters were about 0·34 mm for drift particles and 1·52 mm for new snow particles. Diunin also found that, on striking the surface and being sifted in the saltation zone, the precipitating snow particles were quickly fragmented into smaller particles with the normal drift particle size distribution. In Antarctica, where precipitation tends to be light, it is unlikely that the addition of precipitating snow to drifting snow would introduce substantial shape errors in photoelectric drift gauging. It has in fact proved quite difficult so far to detect precipitating snow particles among drift particle replicae collected by Battye (1964).

VI. INSTRUMENTAL PROBLEMS ENCOUNTERED WITH PHOTOELECTRIC DRIFT GAUGING AND THEIR SOLUTION

Some difficulties encountered with the photoelectric drift gauge were mentioned in Section II(*c*). These are now discussed in more detail in VI(*a*), and a new drift gauge design incorporating some improvements is described briefly in VI(*b*).

(*a*) *Instrumental difficulties*

The greatest difficulty encountered with the prototype photoelectric drift gauge was the instability of the light source. The detecting circuit was extremely sensitive to small variations in light intensity due to:

(i) vibrations of the lamp filament due to wind buffeting on the measuring head, and
(ii) drift in the constant voltage supply to the lamp.

Problem (i) calls for a lamp with a more rigid filament; this has been found in a Philips type 6103R projector bulb. Problem (ii) has been largely overcome in further tests carried out at Mawson during 1963 by E. Wishart of the Antarctic Division, Department of External Affairs. Wishart has restored some of the design features of the original phototransistor gauge (Section II(*b*)) to the photoconductor gauge. In his version of the instrument, a second photoconductor is illuminated by the same light source through a tube protected from the drift. The two photoconductors, both operating at approximately the same impedance, are connected in a balanced bridge circuit. Light attenuation by snow drift will unbalance the bridge and the out of balance current can then be amplified. It appears that this arrangement gives much greater stability. Wishart has also used a constant current supply for the lamp, in place of the constant voltage one, which has resulted in greater stability in view of the operating colour temperature of the lamp filament. Details are given in the second paper of this report.

The principal remaining difficulty arises from the effects of ambient light. These can be reduced in two ways. The first is by increasing the intensity of illumination on the photoconductor by means of a collimating lens and reflector. The second involves the use of infra-red filters. During snow drift the ambient light spectrum is weak in the infra-red; on the other hand the cadmium sulphide photoconductor has a strong response in precisely this region of the spectrum. Infra-red filters would thus reduce ambient light effects to a minimum.

(*b*) *An improved drift gauge design*

The improvements discussed in VI(*a*) have been incorporated in a new photoelectric drift gauge design prepared by the authors. In this gauge an aged Philips 6103R, 30 W, projector bulb is used in conjunction with two Philips B873103 cadmium sulphide photoconductors. The configuration of the components in the head is illustrated in Figure 7. The gauge is designed to operate entirely from 12 volt accumulators to facilitate its transportation and use in the field.

VII. CONCLUSIONS

The photoelectric metering of wind-blown snow has been shown by the tests made during 1962 at Mawson to be entirely feasible. The main difficulties encountered during these tests, concerning light stability and ambient light effects, have since been overcome by improved circuitry and other design modifications.

The principle of photoelectric drift gauging has been shown to present two fundamental difficulties. The first arises from the non-linearity of the relationship between light attenuation and drift density for larger values of the latter. The second is due to the dependence of light attenuation on particle size distribution because of the variation which occurs in that distribution with changes in both height and wind speed. As a result of these difficulties the interpretation of the photoelectric output, in terms of drift density, is not straightforward for measurements made near the surface, where drift density tends to be high and rate of change of particle size distribution with height is rapid. It has been shown, however, that a definite interpretation is always possible and, moreover, that for heights above the 100 cm level, the deviations from a simple proportionality between gauge output and drift density will be within the limits set by the accuracy of the system.

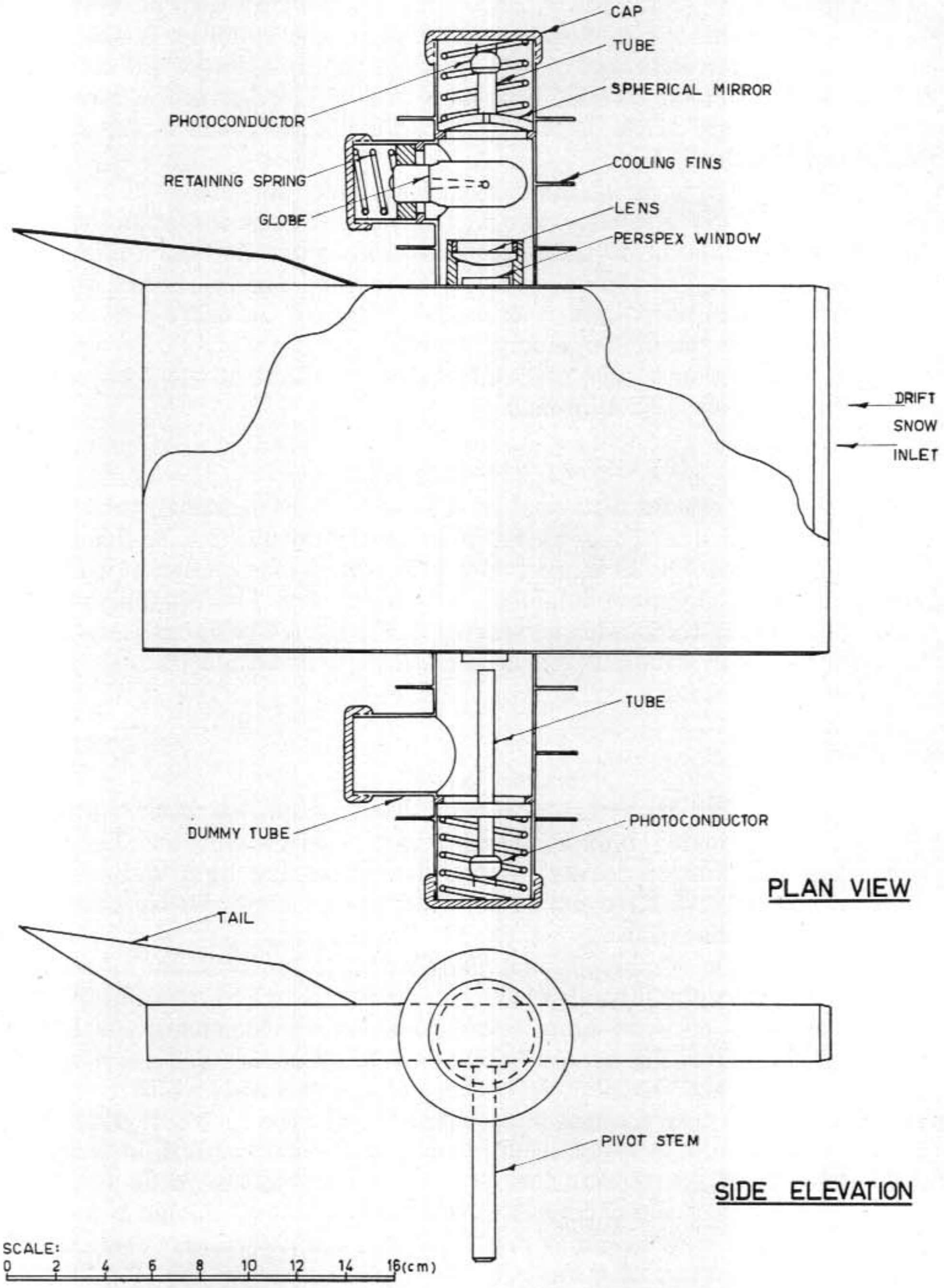

FIG. 7. Sectioned illustration of the measuring head of the new design of photoelectric drift gauge.

Making allowances for the difficulties discussed, it can be claimed that the photoelectric method has many advantages over the drift collectors used to date. It permits the continuous recording of drift density during all periods of drift at a particular site and measurements can be made at greater heights above the snow surface than has so far been feasible. It is hoped also that new fields of drift study will be possible such as density measurements made along the path of the wind to investigate differential erosion and accumulation of snow, as suggested by the study of accumulation on an undulating ice cap surface by Black and Budd (1964).

It can be expected that with some further development a photoelectric drift gauge will become a standard glaciological/meteorological instrument for use in polar regions.

VIII. ACKNOWLEDGEMENTS

The authors are indebted to Dr. U. Radok of the University of Melbourne, Dr. F. Jacka and Mr. W. Budd of the Antarctic Division, Department of External Affairs, Melbourne, for their suggestions and advice which helped to make this project possible. They wish to thank Mr. E. King-Smith of the University of Melbourne and Mr. A. W. Barnett of the Australian Paper Manufacturers Ltd. for suggestions made during initial stages of this work.

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A NEW PHOTOELECTRIC DRIFT SNOW GAUGE

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[Manuscript received April 1965]

ABSTRACT

A photoelectric drift snow gauge is described incorporating features which overcome some of the short-comings of the design of Landon Smith and Woodberry (1965).

CONTENTS

I. INTRODUCTION

Photoelectric arrangements for the metering of wind-blown snow have recently been constructed and described independently by a number of workers (Belov, 1960; Orlov, 1961; Landon Smith *and* Woodberry, 1965; cf. also Annual Report 1962. Department of Meteorology, University of Washington, Seattle). A further photoelectric (PE) gauge here to be described was designed and built by the author whilst at Mawson with the Australian National Antarctic Research Expeditions in 1963 when it was found that the gauge Landon Smith and Woodberry had built there the year before suffered from a number of shortcomings. These included sensitivity to ambient light and general instability in the form of random zero drift. While the new design reduced most of these difficulties it left further room for improvements which will be indicated below. Nevertheless its operational value was proved in a series of calibration runs using as standard one of the rocket traps described by Mellor (1960) and extensively employed in Antarctic snow drift studies (Dingle *and* Radok, 1961; Budd, Dingle *and* Radok, 1965).

II. CONSTRUCTIONAL DATA

A black diagram of the 1963 PE drift gauge is shown in Figure 1.

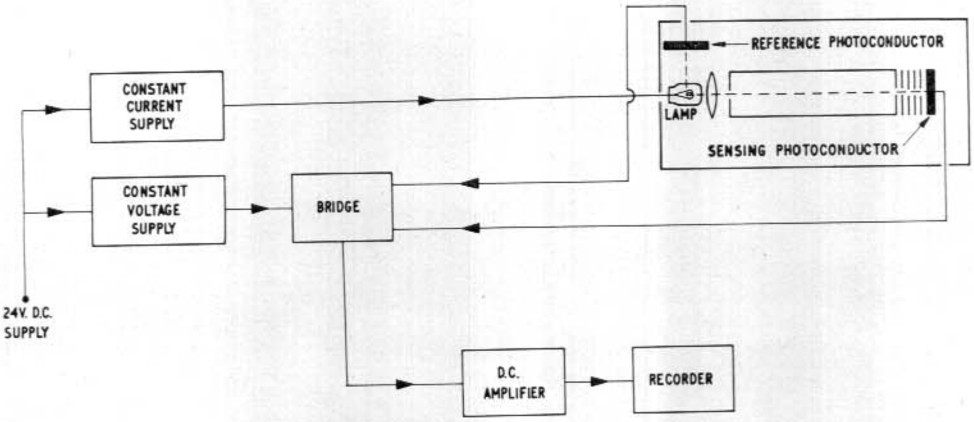

FIG. 1.—Block diagram of drift density gauge.

To reduce effects of ambient light, a series of light baffles was placed in front of the cadmium sulphide photoconductors, RCA type 7163. The light intensity was increased by means of a simple collimating lens. In order to reduce the sensitivity of the photoconductors for short wavelengths a yellow filter was placed in front of each photoconductor.

The pair of photoconductors were selected to have similar sensitivity. Tests showed that a change of 50 mA in the lamp current produced an unbalance of less than 1 mV in the output of the two photoconductors when illuminated under identical conditions.

A heavy-duty projection lamp (12V, 36W) of rigid construction was chosen to overcome the difficulties of filament vibration experienced by Landon Smith and Woodberry. This lamp was aged for about 10 hours and subsequently operated at 2·7A, supplied by the constant-current supply. It was found that a change in input voltage from 22 to 26V (supplied by lead acid batteries, giving nominally 24V) changed the current through the lamp by less than 10mA.

All the elements of the bridge were operated by a simple constant-voltage supply. The output of the bridge was amplified by the DC amplifier to drive a chart recorder which produced curves of the out-of-balance bridge voltage due to the drift snow passing between the lamp and one of the photoconductors.

III. TESTS AND CALIBRATION RESULTS

Exposure of the gauge to direct sunlight in absence of drift produced no measurable unbalance of the bridge.

To establish the zero position, wooden blocks were placed at each end of the gauge tube (Plate 1) to prevent the entry of snow. Under these conditions after switching on, the photoconductors were found to require 3 hours to settle down to a minimum zero drift, which was at the rate of approximately 10 mV per hour. This value, of drift, is equivalent for this

ANARE photo E. Wishart.

PLATE 1. PE gauge and Mellor rocket trap set at the one level for calibration.

instrument to less than a density of *2 gm* m^{-3}. Thus this proved annoying in only light drifting conditions. During operation of the gauge the same blocks were placed into position at hourly intervals to check the zero level.

A total of 21 calibration runs each lasting 1-1·5 hours was made at a height of 1 m above the snow surface, with a Mellor (1960) rocket trap as reference. The results of these measurements are shown in Figure 2 and can be described by the least-square regression relations:

$$\log\,(\mathrm{PE}) = 0{\cdot}95 \log n_M - 0{\cdot}82 \qquad \text{and } (\mathrm{PE}) = 5{\cdot}62\, n_M + 1{\cdot}0$$

where (PE) is the gauge output (bridge unbalance in mV) and n_M the snow drift density or concentration in gm/m^3 as measured with the Mellor trap. The scatter of the points around the regression line in Figure 2 represents a residual variation of 61% ; but it must be kept in mind that the Mellor trap results would not be fully reproducible under given drift conditions. Thus the PE gauge may be regarded as giving equivalent results, for practical purposes.

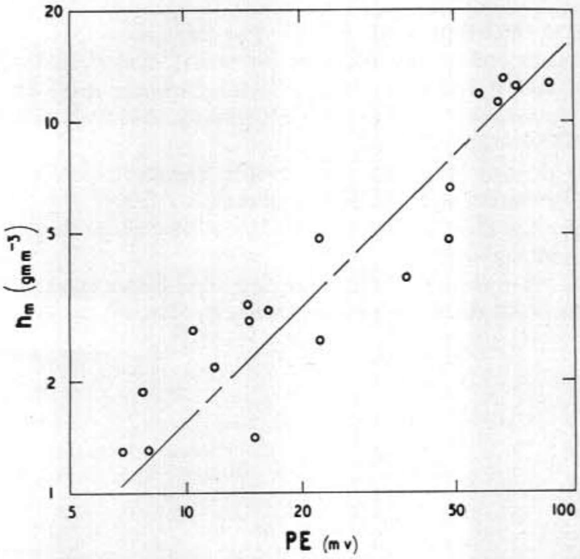

FIG. 2.—Calibration curve, constructed on the basis of comparison of bridge voltage unbalance and actual densities obtained from Mellor trap.

IV. DISCUSSION

The major weakness of the PE gauge described above is the extensive period required to stabilize the photoconductors and the need for frequent zero checks particularly under light drift conditions. Nevertheless, the stability achieved is a considerable improvement on the original Landon Smith and Woodberry gauge.

It should be noted that the cadmium sulphide photoconductor Type RCA 7163 (which happened to be available at Mawson) normally is used for "on-off" control devices rather than for continuous control. Hence the gauge may be expected to perform better with a more stable light-sensitive device, such as a conventional vacuum photocell, or silicon photovoltaic cell, in place of the cadmium sulphide photoconductor. On the other hand the use of stabilized supplies and of light baffles appears to have eliminated some of the difficulties experienced by Landon Smith and Woodberry (1965) and the comparisons with the Mellor trap demonstrate that photoelectric metering of wind-blown snow is definitely an operational possibility.

This does not exclude, of course, possible major design improvements. In fact Landon Smith and Woodberry gave an outline of a modified design which has not yet been tested.

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