RESEARCH TECHNICAL COMPLETION REPORT
PROJECT A-008-IDA

Physical State Properties Of Precipitation

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Research Assistant J. C. Read

Water Resources Research Institute
University of Idaho
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PERIOD OF INVESTIGATION - March 1965 to June 1966

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Water Resources Research Institute
University of Idaho
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ABSTRACT

The object of this research was to study the properties of snow or rain in the falling state that would permit positive identification of the state of the precipitation. The ultimate application was to provide a record of when it was raining or snowing and to provide a means of relating the record to conventional recording precipitation gage records.

Various properties of precipitation were evaluated both by literature search and by laboratory investigation. Properties investigated included conductivity, storage of static charge, impact momentum, acoustic energies, and both optical reflectivity and opacity.

Optical reflectance proved to have the most promise and a scheme for making such a measurement was proposed. Subsequent to this a prototype device was developed.

McKEAN, G. A.

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KEYWORDS: Precipitation*, Rain*, Snow*, Precipitation Gages*,
Precipitation (Atmospheric), Rainfall (Impact),
Rainfall Distribution

OBJECTIVES AND PURPOSES

In various hydrologic studies it is often important to know the time and amount of precipitation in both forms of rain (liquid phase of precipitation) and snow (solid phase of precipitation). Particular needs had been pointed out by research in progress by the Intermountain Forest and Range Experiment Station and by studies of snow measuring devices being developed by the University of Idaho, Engineering Experiment Station.

The specific objectives of the research was to find a suitable property or properties of snow or rain in the falling state that would permit positive identification of the state of precipitation and provide a means of developing a record discriminating whether it was raining or snowing.

PROCEDURE

A search of literature was first made and this revealed no specific device capable of making a discrimination of snow and rain. Three references did suggest possible means if modifications were made.

One such device which is a modification of what is known as the Barnothy and Bell method, is basically an alarm system which is activated whenever a water droplet strikes a blotter paper which enclosed a heated metal cylinder (Illinois State Water Survey, 1964). The droplet wets the blotter and thereby increases the electrical conductivity between the cylinder and an outer wire winding. This increase in conductance is used to increase the grid bias on a thyratron, causing it to fire. A recorder relay coupled to the plate circuit of the thyratron is then used to furnish the output information. Because the interior cylinder of the detector is heated, the moisture absorbed by the blotter will eventually evaporate. The thyratron bias is then lowered to a value at which the tube ceases to conduct, and the system is then ready to detect another water droplet.

Although this system is not designed to discriminate between phases of precipitation, it does present a possible method of achieving this, especially if a trap could be devised which would allow only one of the phase types to reach the detecting element.

Another possible means of snow detection is suggested by various literature sources concerning the measurement of the static electric charges contained by various snowflakes. Data on such measurements are erratic and various experimenters working at different locations and times have produced markedly different results. Polarity, magnitude and statistical distribution of the charges carried by snowflakes apparently vary with the size of flakes, temperature, rate of snowfall and other characteristics of the storm (Nakaya, 1954 and Chalmers and Pasquill, 1938).

In one experiment to measure the charge of falling snowflakes in Japan, an electrostatic deflection system was devised (Nakaya, 1954). A snowflake passing through an electric field between parallel charged plates would be deflected in accordance with its charge magnitude and polarity. Although rain also is known to have a charge distribution among droplets, data do not show charge magnitudes for rain droplets to be significantly greater than for snowflakes (Chalmers and Pasquill, 1938). The possibility arises that if precipitation particles were made to pass between charged plates, the electrostatic deflection would be greater for snow than for rain due to its inherently slower velocity. Mass and air resistance are also phase characteristics which would affect the amount of particle deflection. Catch containers could then be placed in a position that is sufficiently offset to allow only deflected snow particles to collect there.

A third precipitation detection technique, a minor variation of which is the subject of the primary consideration of the M. S. thesis by Read, is an optical method employed by E. Bollay Associates, Incorporated, of Boulder, Colorado, in their snow-rate detection scheme (Zopf, 1965). Although specific details of the "snow-rate sensor" are not known, it is basically described as an optical attenuation device. A parallel light beam is produced by a flashlight-type reflector and is directed to a photosensitive surface of the detection system. The system functions basically from the attenuation of light incident upon the detector due to the presence of falling precipitation particles in the light beam. A personal communication from E. Bollay Associates, Incorporated, indicates that as of June 22, 1965, the rain detection capabilities of the device had not been assessed.

In addition to the approaches suggested in the literature search, certain other ideas were investigated. All of these involved a measurement of different physical properties of snow and rain in the falling state. These methods included measurement of dielectric properties, impact momentum, acoustic energies transmitted through fliud in a receiving receptacle upon impact of a precipitation particle, and optical reflectivity as opposed to optical transmission attenuation suggested in the literature search.

RESULTS

In screening the possibilities for a promising system the following information was used to make a selection:

Data on dielectric constant of precipitation particles were found to vary so widely and problems of collection and sampling made dielectric properties a negative possibility. Likewise measurement of impact momentum appeared to be infeasible due to possible interference from wind-caused vibrations. A comparison of snow and rain particle momentum shows an overlap among lighter rain droplets and heavier snow crystals.

In an experiment to measure the electrostatic deflection of snowflakes, a field strength of 1300 volts per centimeter was found adequate to produce what was termed "moderate" deflection to the paths of sufficiently charged snow particles. Although the term "moderate" is vague, it appears from a photograph that sufficient deflection was produced in more highly charged particles to cause them to strike one of the deflection plates within a 65 centimeter vertical fall when entering approximately midway between parallel plates spaced 30 centimeters apart. Although it does appear possible to separate rain from snow in this manner, the high field strength required is a disadvantage. For the physical dimensions described the potential differences of the places would have to be 39,000 volts to produce the field strength of 1300 volts/cm. A plate separation of 30 centimeters might not be required, but any reasonable plate separation would require the use of voltages higher than would be desirable in a field instrument. Also snow and rain particles must fall vertically between the plates to produce accurate results. During windy periods the use of chimney catches or shields would be required which add awkward physical dimensions to the size of the instrument. The chimney used in the experiment described was 420 cm long and 54 cm in diameter.

The Barnothy and Bell type of detector does not appear to be useful for the purpose of phase discrimination. This is because of difficulties involved in designing a trap that would allow only one of the two precipitation phases to reach the detector element. A shielding system is recommended in the mentioned report that aids in the detection of snow; however, whether the detector is shielded or not, it is still capable of intercepting a particle of either precipitation phase.

General opaqueness of snow and transparency of rain are two optical properties of the phases of precipitation that offered promise. Difference in reflectance and optical attenuation were also found to be possibilities. For this reason special experiments were performed to determine possibilities in this realm.

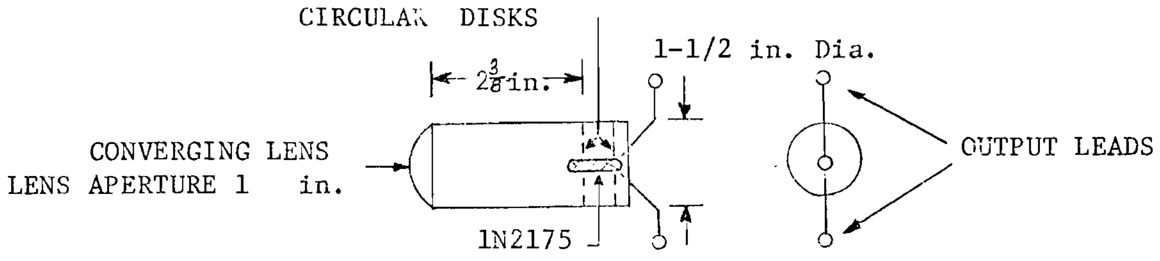
Initial Optical Experiments

The reflectance of fresh snow varies as a function of wave length; however, for the visible wavelengths of from 0.4 to 0.7 micron, the reflectance varies only in the range of from 92 to 95 per cent (Mellor, 1964). Although these data were obtained from tests using settled snow, the high percentage of luminous energy which is reflected for these wavelengths does enhance the possibility of distinguishing snow reflectivity from that of rain.

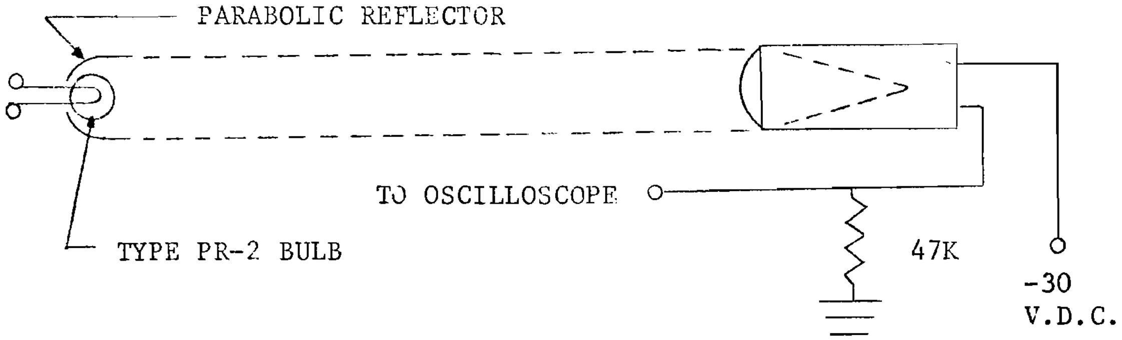
Experiments were performed to measure the effects of light reflection and attentuation on a photosensitive device for rain and snow. Because these tests were not made during a snow season, one-quarter inch squares of white paper were used to simulate snow. It was assumed that the reflectivity of natural snow could not be significantly less than that of the paper particles.

A 1N2175 type photodiode made by Texas Instruments, Incorporated was used as a light detector. The 1N2175 is a subminiature, solid state silicon unit. It is cylindrical in shape and is approximately 0.6 inch long and 0.082 ± 0.003 inch in diameter. A focusing lens is self-contained in the head of the unit. Typical illumination sensitivity is about 0.6 microampere per foot-candle of light intensity. Peak sensitivity occurs at about 0.97 micron; however, the response is above 50 per cent at 0.60 micron. Characteristic curves and other pertinent data are contained in the thesis by Read, 1966.

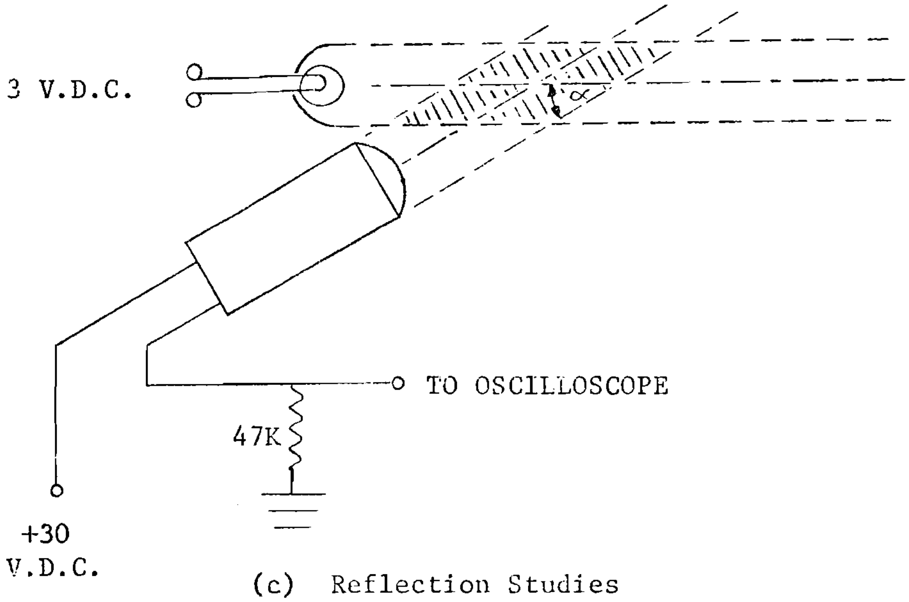
A housing for the 1N2175 was constructed of a cardboard tube 1.5 inches in diameter. A focusing lens was mounted 2.375 inches ahead of the light



(a) 1N2175 Photodiode Housing



(b) Attenuation Studies



(c) Reflection Studies

Figure 1. Layout of Initial Experiments

sensor so as to focus a parallel light beam, incident upon the lens aperture, onto the lens head of the 1N2175. The lens opening was 1.125 inches. A diagram of this mounting system is given in Figure 1a.

The light source for this experiment was an ordinary flashlight using a General Electric type PR-2 bulb, powered by two D size flashlight batteries.

In order to measure the optical attenuation effects of water droplets and simulated snow on the diode, the apparatus was arranged as indicated in Figure 1b. Water droplets supplied through a pipette dropper and the white paper particles were made to pass through the light beam, and the effect was observed on the oscilloscope.

It was noted that both the paper particles and the water droplets produced output pulses varying in the range of from 0.2 volt to 4.0 volts. No basic differences in the output voltage magnitudes were noted. Both the water droplets and the paper particles produced high and low voltages in the range indicated, and in a random manner. A probable cause of the fluctuations in output magnitude is differences in the amount of light attenuation caused by particles passing through different portions of the beam.

From this portion of the experiment it was concluded that optical attenuation offered no means of discrimination of precipitation phase.

Reflective effects were observed by positioning the detector in a position so as to scan the light beam as is indicated in Figure 1c. It should be noted that as "alpha", the included angle between the detector and light beam axes, is made smaller, the portion of the light beam which the detector scans becomes larger. As the paper particles were passed through portions of the beam indicated by the shaded area in the figure, random outputs were observed varying from 0.5 millivolt to 4 millivolts. The orientation of the plane surface of the paper particle with respect to both the light source and the detector determines, to a large degree, the amount of reflected light which is received at the detector.

No observable output was noted as water droplets were passed through the beam during these initial experiments. As is later explained, water droplets do produce significant voltages when passed through a certain critical area of the beam. The critical area indicated, however, is considerably smaller than the area for which the detector is sensitive to the paper particles.

Optical System Functional Scheme

Although a system based on optical attenuation in itself does not appear capable of solving the problem, its use in conjunction with a reflected light detector in detecting and distinguishing both rain and snow can be shown. If a detection system is assumed to consist of a diode to sense light attenuation, a diode to sense reflected light, and a unit to perform an analysis of the two sensor outputs, a form of logic may be derived which enables the distinction of precipitation phase. The reflected light sensor is referred to as "source A", and the attenuated light sensor is referred to as "source B".

In accordance with the experiment previously explained, an output is obtained from source B for the presence of either rain or snow. With proper geometric arrangements, source A can be made sensitive to snow only, and therefore an output from this source dictates the presence of snow regardless of the presence or absence of an output from source B. Table I presents the logic necessary for a proper decision to be made by the analyzer unit.

Table 1

OPTICAL SCHEME LOGIC

Outputs Present		Conclusion
Source A	Source B	(Phase Present)
Yes	No	Snow
Yes	Yes	Snow
No	Yes	Rain
No	No	None

One inherent source of error is the possibility that a snow particle may fall with such an orientation that it is sensed by the B diode, but not by the A diode. In this case it would appear that a rain droplet were present instead of snow. It is possible to mistake snow for rain with this system; however, the possibility of mistaking rain for snow is made remote with proper geometric arrangements. Since system errors of only one type occur, this system is compatible for the desired phase discrimination functioning because the intermixed appearance of snow and rain characteristic outputs would indicate snow. Rain could be distinguished by the repeated appearance of its characteristic output without the appearance of a snow detection error.

One other factor further complicates the usage of this logic system. Assuming that, in the event of the presence of a snow flake, both A and B outputs are obtained, there is no assurance that both outputs will occur simultaneously. The phasing of the outputs is entirely arbitrary and must be considered when utilizing this logic method. Should the B output occur first, it would appear for a short time that the particle were a rain droplet.

From the logic presented in Table 1, a functional system was devised and built which is capable of performing the desired logic and is also inherently free from the problems presented by phase differences between the timings of the sensor outputs. The system is shown in block diagram form in Figure 2.

Because of the low level of the outputs from source A, an amplifier is first employed to raise these outputs to a usable level. The amplifier gain is approximately 1000. Because outputs from the B diode are considerably higher than those of the A diode, it was not found necessary to amplify these signals. Actual circuit diagrams for the amplifier and other circuits are found in the thesis by Read, 1966.

The system utilizes the monostable multivibrator. The advantage of this device is that it is permanently stable in only one of two possible states. When it is properly triggered by an input signal the multivibrator regenerates into its stable state and exists in that condition for a controllable length of time, and then returns to its permanently stable state until it is again triggered. The resulting output is a single square shaped pulse for each trigger that is applied to its input. The period of the output pulse is controlled by an RC discharge circuit within the multivibrator itself.

The signals from source B and the amplified signals from source A are used to trigger multivibrator B and A respectively. When triggered, multivibrator B produces a 7.3 volt output of 25 milliseconds duration. The outputs of both multivibrators are fed into a passive OR circuit. An OR circuit gives an output whenever an input of the proper polarity is present at any of its inputs. Also, this output magnitude will be the same as the largest voltage present at any of its input terminals.

Because of the commanding influence of a signal from the A source (an input from source A represents snow regardless of the state of source B), a

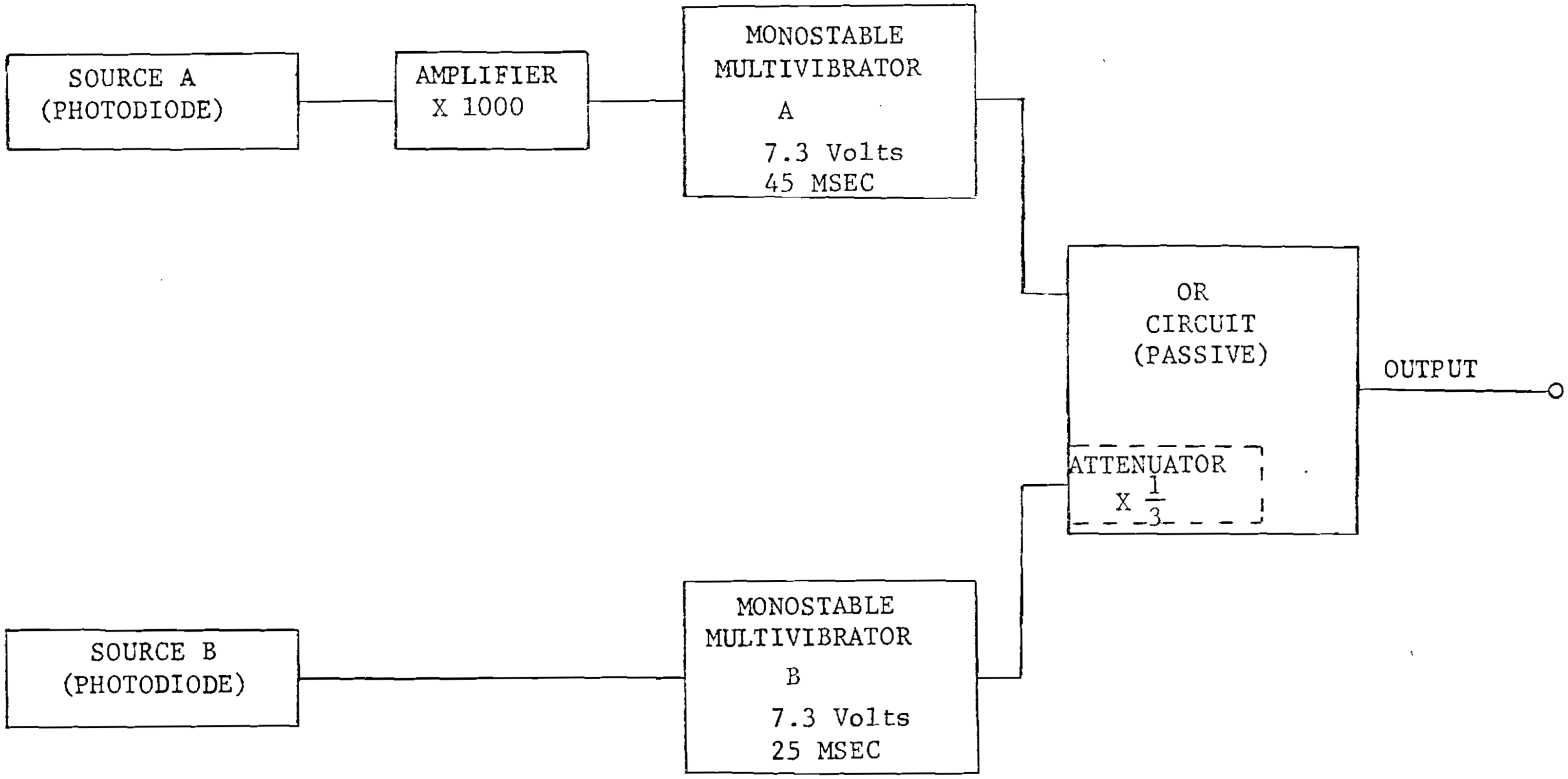


Figure 2. Optical System Functional Diagram

resistive attenuation circuit is employed within the OR circuit which reduces the level of the OR circuit output when stimulated only by the B multivibrator to a value which is approximately 1/3 of the original B multivibrator output magnitude. The result is that when multivibrator A is triggered the OR circuit output is a 7.2 volt pulse of 45 milliseconds duration. This is the characteristic output obtained when snow is sensed by the A diode. The slight attenuation of the multivibrator output from 7.3 to 7.2 volts is due to the conduction resistance of the diode used in the OR circuit. When multivibrator B alone is triggered, a 2.3 volt output of 25 milliseconds duration is obtained at the OR circuit. This output is characteristic of the sensing of rain. Should both multivibrators be triggered simultaneously, the result is the same as though only multivibrator A were triggered. This is because of the commanding influence multivibrator A has on the output of the OR circuit.

In this manner, problems caused by the time phasing of the triggering of the two multivibrators are overcome. It is inconsequential if the B output is received at the OR circuit slightly before or after the A output since the 7.2 volts output due to the sensing of snow is easily distinguishable once it does occur.

It should be noted that source A, the amplifier, and multivibrator A compose a completely functional scheme since this portion of the system can be rendered sensitive to snow only. As was mentioned previously, only one of the two possible phases needs to be detected when used in conjunction with a precipitation accumulation recording device.

System Layout and Geometric Characteristics

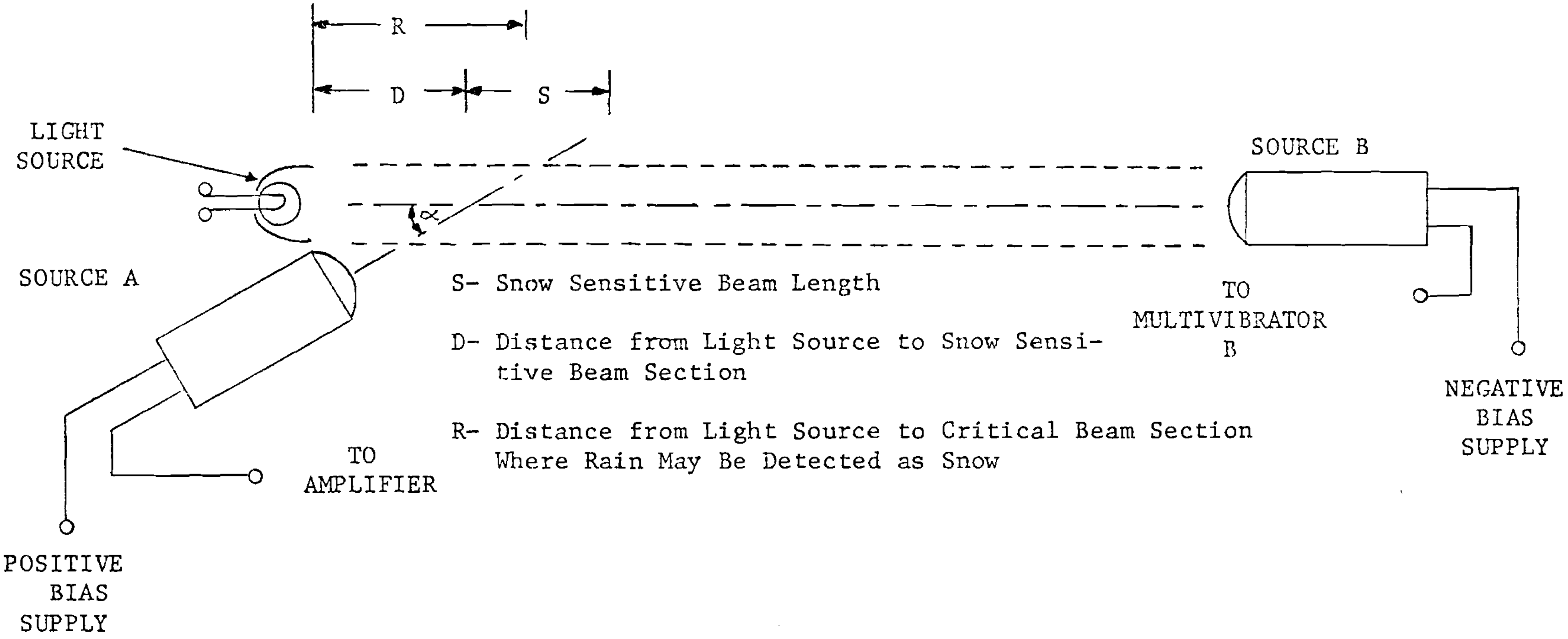
To study operational characteristics an arrangement for the photodiodes and the light source were made as illustrated in Figure 3. The photodiode housings and light source were mounted on ring stands to permit easy manipulation of geometric parameters involved.

As was mentioned previously, water droplets passing through certain sections of the light beam produce outputs from source A which are of the order of magnitude of those outputs produced by simulated snow particles. Experiments with the developed circuitry demonstrated that these outputs were sufficient to cause triggering of multivibrator A when the water droplets were passed through a certain critical section of the beam. The beam length for which multivibrator A is sensitive to triggering resulting from water droplets was found to be difficult to measure. This is because not every droplet passed through this critical section produced an output pulse. In some cases as many as ten droplets were required to produce one output from multivibrator A. The distance from the light source to a point at which the system is initially subject to erroneous detections of rain for snow is designated "R" in Figure 3.

As the angle between the axes of photodiode A and the light source is lessened, the beam length for which the system is sensitive to simulated snow is increased. This angle is referred to as "alpha", and is illustrated in Figure 3. The distance from the light source to a point at which source A becomes sensitive to snow particles is designated "D" in the figure. The section "S" is the beam length for which source A is snow sensitive.

An experiment was arranged to determine the functional relationship between R, D, S, and alpha. System outputs were observed on a Tektronix 503-type oscilliscope. Since all of the variables measured in this experiment are defined with respect to effects observed at multivibrator A, photodiode B was not used for this portion of the experiment. A 1/4 by 1/4 inch slice of styrafoam-type plastic was used to simulate snow instead of the paper particles previously used. The styrafoam particle was attached to the end of a long black wire, thus enabling good control of the location of the particle as it was manually passed through the beam. Water droplets were issued from a medicine dropper.

The distances R, D, and the sum of D and S were measured for various values of alpha in the range of 10 to 45 degrees. From these data S was calculated. The results are tabulated in Table 3 below. A plot of the beam length as a function of alpha is shown in Figure 4.



S- Snow Sensitive Beam Length

D- Distance from Light Source to Snow Sensitive Beam Section

R- Distance from Light Source to Critical Beam Section Where Rain May Be Detected as Snow

Figure 3. Operational Configuration Illustrating Geometric Parameters

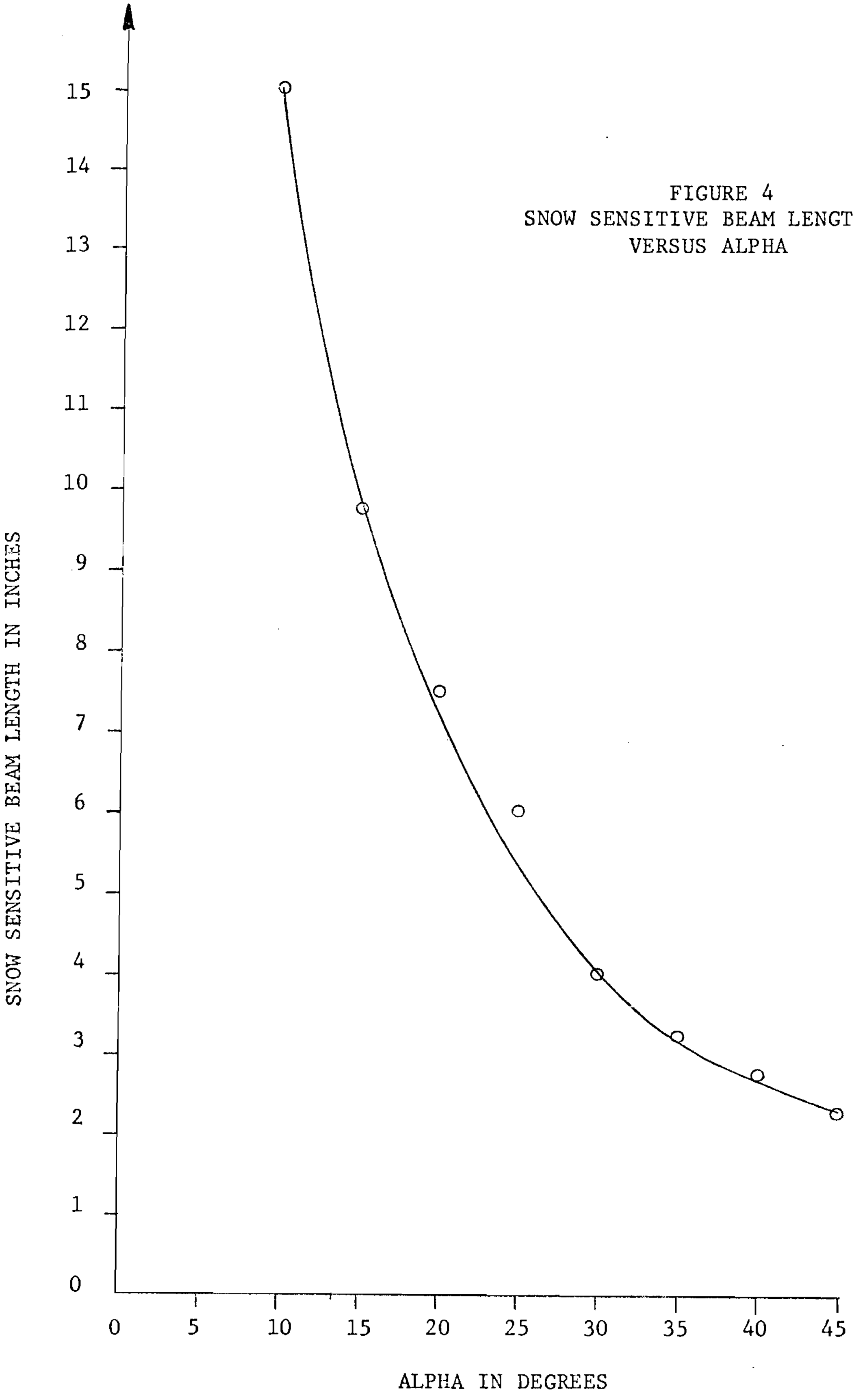


FIGURE 4
SNOW SENSITIVE BEAM LENGTH,S,
VERSUS ALPHA

Table 3

GEOMETRIC CHARACTERISTICS OF OPTICAL SYSTEM PERFORMANCE

Alpha (degrees)	D (inches)	S - D (inches)	S (inches) (calculated)	R (inches)
10	5-1/2	20-1/2	15	9
15	3-1/2	13-1/4	9-3/4	6
20	3	10-1/2	7-1/2	5-1/2
25	2-1/2	8-1/2	6	4
30	2	6	4	3-1/4
35	1-1/2	4-3/4	3-1/4	3
40	1-1/2	4-1/4	2-3/4	2-1/4
45	1-3/8	3-5/8	2-1/4	2

It was noted while determining the snow sensitive beam length, that the sensitive area was roughly a parallelogram as is shown in the shaded cross sectional beam area illustrated in Figure 1c. Assuming a constant beam width (non-divergent) the total cross sectional area for which the instrument is snow sensitive is then proportional to the beam length S. The beam width of the light source used in this experiment was approximately two inches. The sensitive cross-sectional area for an alpha of ten degrees is then approximately 30 square inches.

The critical section at which multivibrator A was triggered by water droplets was found to occur within the snow sensitive area for every angle tested. The length of this section was not recorded due to difficulties in producing these erroneous outputs. This length was never observed to be greater than one inch in any case except when the intersection angle, alpha, was set equal to ten degrees. In this case, detection errors were observed for approximately two inches of the beam length. In a functional system, this section would have to be shielded from precipitation particles to assure reliability of results.

Nature of Recorded Outputs

In order to demonstrate the manner in which rain is distinguishable from snow on a graphical recording, a model 135A, X-Y recorder made by the Moseley

Company was connected to the OR circuit output. The operational configuration was arranged for an alpha of ten degrees, since a greater snow sensitive beam length is obtained for lesser values of alpha. The distance from the light source to the lens opening of the photodiode B housing was set at 15 inches. A 30 volt supply was used to supply photodiode B. The bias current was 0.6 milliampere. The simulated precipitation particles were passed through the beam and characteristic detection outputs were observed on the recorder. Care was exercised to assure that no water droplets were produced in the area from nine to eleven inches from the light source to assure that errors were not made due to the water droplet sensitivity of multivibrator A in this section.

Three of these recordings are illustrated in Figure 5. The different recordings of the figure are (a) characteristic snow detection output for a 12 volt, photodiode A supply, (b) characteristic snow detection output for a 30 volt, photodiode A supply, and (c) rain detection characteristic output. For the recordings the functional sensitivity of the recorder was set at one volt per inch of deflection. A time sweep of five seconds per inch was used.

The recorder responded to water droplet detections with recorded pulses of about 0.35 inch. The snow detection response was a recorded pulse varying in height from 0.70 inch to 0.85 inch. The differences in these pulse heights are due to the presence or absence of outputs from multivibrator B occurring slightly before or after an output from multivibrator A. With photodiode B disabled, it was found that the snow detection output recorded pulses were consistently 0.70 inches in height. The snow detection outputs are easily distinguishable from the rain detection outputs, however. Due to the short duration of the output pulses, the recorder did not respond entirely to a height representative of the output pulse magnitudes.

Random errors were detected for the snow recordings. Snow detection was distinguishable from that of rain, however, by the intermixed appearance of snow and rain characteristic outputs. It was found that the snow detecting capability of the instrument was dependent upon the orientation of the particle as it fell through the sensitive area. Particle orientation was difficult to regulate since the particle was manually manipulated. In general it was observed that best results were achieved when the particle was placed with the broadside vertical in such a manner as to reflect light toward the detector. Snow detections could be made, however, with a particle held horizontally presenting a reflecting area of about 1/8 inch by 3/32 inch rectangular dimensions to the beam. To detect these smaller particles, it was necessary to pass them in portions of the beam within 7.50 inches of the light source, and also within the detection sensitive area.

Photodiode Supply Voltage Effect

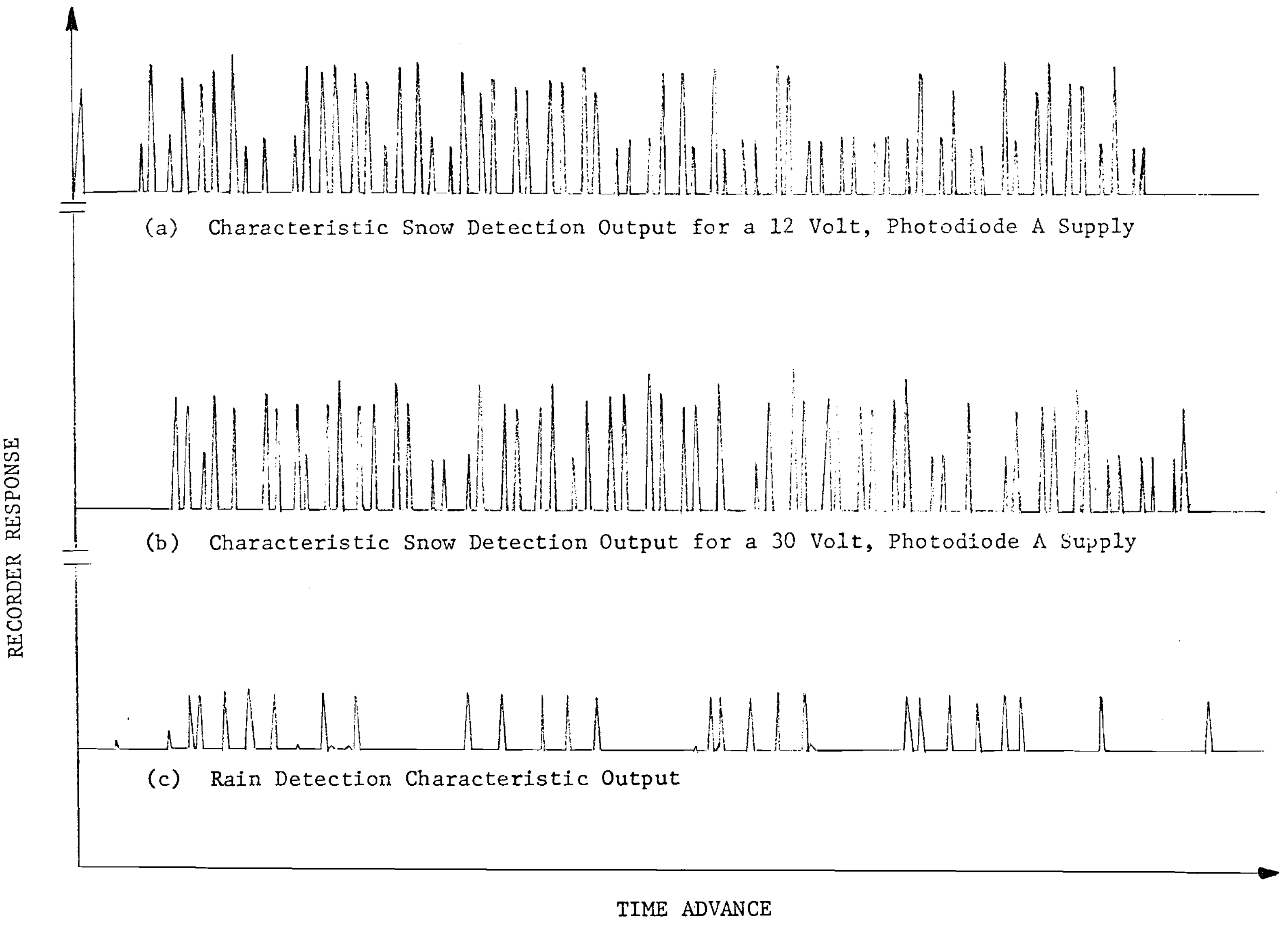
For a given constant illumination intensity, the output current of the 1N2175 remains nearly constant for a wide range of bias voltages. It functions essentially as a current source in a manner analogous to the vacuum pentode. For this reason, the photodiode supply voltage used should not greatly affect the instrument sensitivity as long as a good linear quiescent point is maintained. Photodiode A was found to respond well to supply voltages varying from 2 to 30 volts. The snow detection recordings of Figure 5 illustrate this effect. When a 12 volt supply was used, 35 correct detections and 29 erroneous detections were produced. A 30 volt supply produced 42 correct and 15 erroneous outputs. Although less errors were produced using the 30 volt supply, this improved performance cannot be directly traced to the increased voltage. Errors tend to be produced in uninterrupted succession. For this reason it appears that they result from variations in the simulated snow particle orientation.

Due to saturation effects, the system was found unable to detect water droplets when the photodiode B supply potential was lowered below 18 volts. The tendency of the diode to saturate as the supply voltage is lowered is illustrated in Table 4. In this case it appears that the light source was too intense to produce good operation of the photodiode at low supply voltages.

Table 4

SATURATION EFFECT OF LOWERING PHOTODIODE SUPPLY VOLTAGE

Supply Voltage	Photocurrent (milliamperes)	Bias Voltage
30	0.50	7.0
25	0.46	4.5
20	0.41	0.92
15	0.32	0.09
10	0.22	0.05



(a) Characteristic Snow Detection Output for a 12 Volt, Photodiode A Supply

(b) Characteristic Snow Detection Output for a 30 Volt, Photodiode A Supply

(c) Rain Detection Characteristic Output

Figure 5. Illustration of Recorded Outputs

CONCLUSIONS AND RECOMMENDATIONS

The luminous reflectivity of snow, as compared to that of rain, was found to be a suitable property by which a system may be developed which is sensitive only to the presence of falling snow and not to rain. If both solid and liquid phases are to be detected and identified, the reflective properties of snow may be used in conjunction with the light attenuant properties of both phases to successfully accomplish this function.

Subsequent to this research there was built a prototype instrument that utilizes a modified Belfort recording precipitation gage for snow and rain discrimination for snow and rain. Two reports by Bell, 1967, gives details to this work.

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