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U. S. DEPARTMENT OF AGRICULTURE.

WEATHER BUREAU.

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MEASUREMENT OF PRECIPITATION.

INSTRUCTIONS ON THE MEASUREMENT AND REGISTRATION OF PRECIPITATION BY MEANS OF THE STANDARD INSTRUMENTS OF THE U. S. WEATHER BUREAU.

CIRCULAR E, INSTRUMENT DIVISION.

THIRD EDITION.

(Reprint, 1913.)

Prepared under direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

C. F. MARVIN,

PROFESSOR OF METEOROLOGY.

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INSTRUCTIONS FOR USE OF MARVIN FLOAT RAIN GAGE.

A MECHANICAL RAIN GAGE PROVIDING WEEKLY RECORDS.

Whereas the tipping-bucket rain gage permits of a great refinement and accuracy of record, and is probably the best device available for securing rainfall records at the regular Weather Bureau stations, there is still a widespread need for a thoroughly reliable gage of ample capacity, complete in itself, involving no troublesome electrical arrangements for registration, and finally providing a record covering a considerable period of time. The design of a weekly gage of the float type to meet such requirements was undertaken early in the year 1913 by Prof. C. F. Marvin, and a model constructed and carefully tested. The success of the tests led to the purchase of a number of these gages for use in the Weather Bureau service. They should eventually find an extended use in the studies of rainfall in connection with many projects wherein the *rate* of rainfall is an important factor.

Wind shields of the Nipher type are provided, which will doubtless assist in obtaining the true catch, even on occasions when the wind velocity is considerable.

Description.—Figure 1 shows the complete gage. The collector, A, at the top is exactly 8 inches inside diameter across the brass rim, and is surrounded by the rectangular wind shield, B. This shield is nearly 21 inches square at the upper edge and curves downward and inward to the copper cover, C, to which it is screwed. The cover is about 15 inches square inside and together with the 8-inch collector forms the top, the two being soldered to each other. The cover is ordinarily hinged to the top plate of the support, and is locked in position by a small bolt. The support, E, which is a little over 2 feet high, is made up of two iron castings; one at the top carrying the recording apparatus and cover, and one at the bottom forming the base for the receiver, D. The two castings are connected together

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at the center by a 1¼-inch pipe which also serves to inclose the small brass counterweight. Four small iron pipes at the corners form posts which are screwed into the upper casting and fastened to the lower casting by means of set screws. The lower ends of the corner posts form feet for the gage.

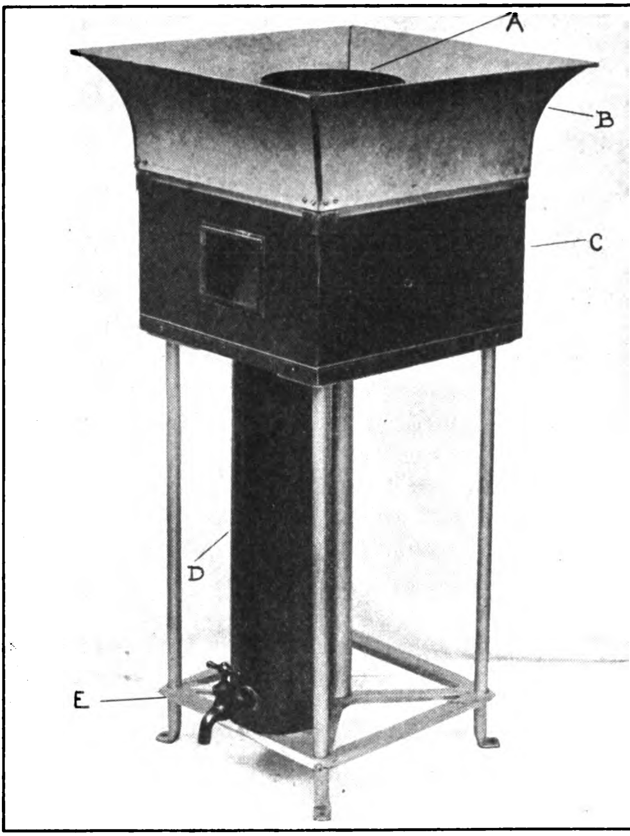

Fig. 1. Gage complete.

Figures 2 and 3 illustrate more clearly the recording apparatus. The registration is a record of the motion of a float upon the surface of the water in the receiver. To eliminate inaccuracies and uncertainties, the float is suspended by means of a fine flexible brass chain such as jewelers use, permanently attached to one end of the drum, H. When the float rises the chain is wound up by the pull of the counterweight suspended from a length of silk cord, also fastened to and wound up on the drum, H. The chain and cord run in a shallow screw thread cut in the drum, and the chain winds up as the cord unwinds, and vice versa. The chain eliminates possibilities of variation of length, such as would be caused by moisture and stretching should a cord be used; moreover slipping is impossible.

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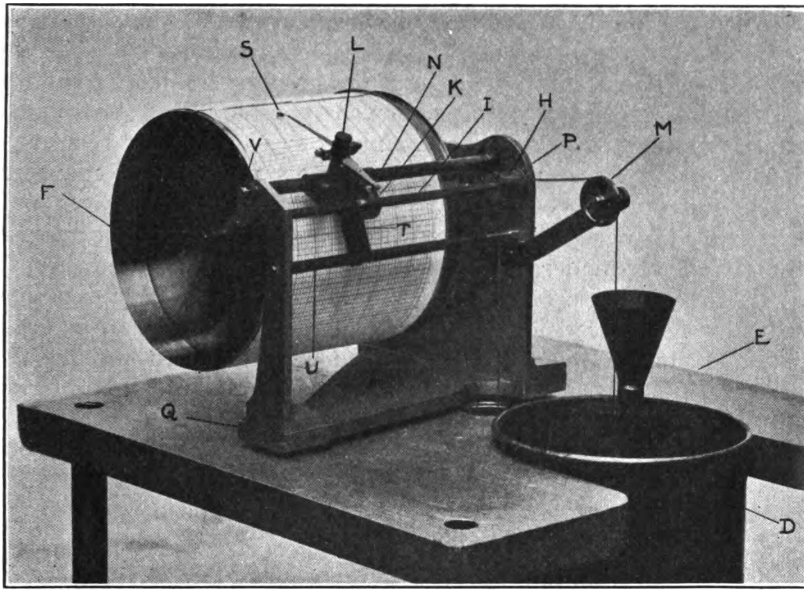

Fig. 2. Recording mechanism of gage, showing pen in position on sheet.

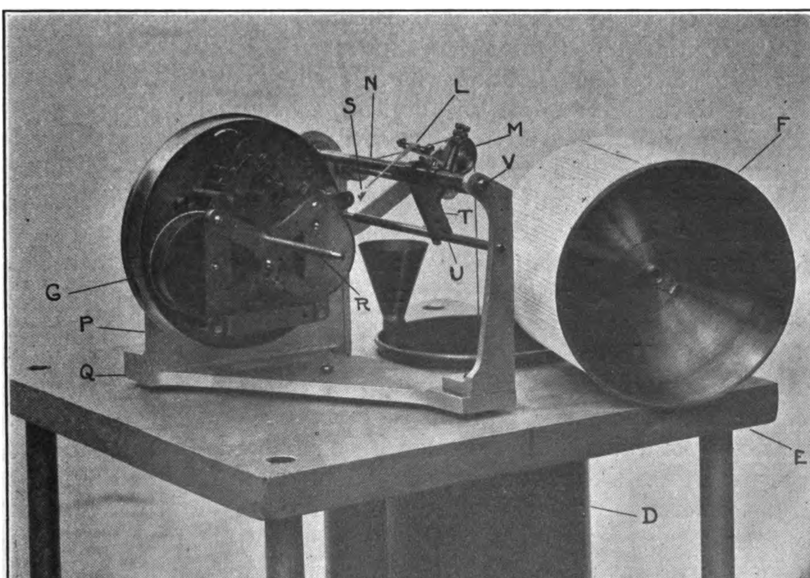

Fig. 3. Recording mechanism with cylinder removed, showing clock.

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The cam shaft, I, carrying the drum, H, turns once for each one-half inch of rainfall, and revolves a cylindrical cam, K, made to turn with the shaft, I, but free to slide endwise at the same time. The pen and pen lever are shown at S and L, respectively. The pen carrier, T, is mounted on the long screw, N, and guided by the rod, U. The motion of the pen is somewhat complex, but the arrangement is one that affords the maximum of clearness of records of excessive rates of precipitation, and at the same time the minimum of size of record sheets. Nearly all other automatic gages with records on a large scale require very large sheets that must be changed after a relatively moderate amount of rain has been recorded thereon. In this gage the rise of the float in the manner already explained rotates the cam, K, which in turn causes the pen to oscillate laterally over an extreme range of one-half inch on the record sheet. This amount of motion, over and back, represents one-half inch of rain. The one-tenth-inch rulings on the sheet represent 0.05 of an inch of rainfall, and permit of very satisfactory estimates to hundreths of inches. The practical impossibility of any kind of accumulative error in this gage makes its records more reliable than gages of the tipping-bucket type.

The adoption of an oscillating motion of the pen enables a large amount of precipitation to be recorded in a narrow band one-half inch wide across the record sheet. The remainder of the sheet is made available for additional record simply by causing the pen carrier to move laterally by the action of the clock at the rate of one-half inch per revolution of the drum. Thus each day's record (one revolution of the drum) occupies only a transverse space on the record sheet one-half inch wide. Each sheet provides a record for eight days. The object of adopting an eight-day record is that four sheets will suffice for a full record for each and every month. Instruments using only seven-day or weekly record sheets require five sheets with little only on one of the sheets. The record cylinder, F, is 6 inches in diameter outside, and $5\frac{7}{16}$ inches in length over all, and it is made to revolve on the axis, R, by the clock, which is entirely inclosed and protected from dust and moisture when the cylinder is in place.

Operation.—The rainfall caught in the 8-inch collector, A, passes through a funnel and a small pipe to the bottom of the cylindrical receiver, D, which has half the sectional area of the receiver, A. The depth of rainfall is therefore only doubled for measurement. Receiver D, has a capacity for nearly 10 inches of rainfall, and may be conveniently emptied by the aid of the spigot provided. This has a siphon-like extension inside the receiver that permits the surplus water within to be drawn off to a certain zero level, but leaves remaining, not only a small quantity of water, but especially a surface layer of kerosene that is added to the receiver when the instrument is installed for the purpose of preventing evaporation. Changes

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in the level of the water are communicated through a float and auxiliary mechanism to the recording pen in the manner explained above.

Although the gage may be continued in operation for eight days without requiring attention, yet occasional inspections during the period will avoid possible failure, as it can hardly be expected that the instrument will invariably give satisfactory service without attention.

Exposure and installation.—The exposure of the gage will conform to the instructions already forming a part of Circular E, Instrument Division. When the gage is installed some kind of a support is necessary, and either a small wooden platform or a surface of concrete will be used. The wooden platform permits fastening the feet of the gage by wood screws sent with the gage. The gage may be secured to the concrete by means of expansion bolts, or other customary methods.

The gages are sent out only after having been carefully inspected, tested, and the clock adjusted to keep correct time. When received, the float, counterweight and clock key will be found wrapped in the bottom of the receiver. The float and counterweight will then be attached to the chain and cord, respectively, which are carefully cut to the proper lengths at the Central Office, so that when the cord is entirely wound up, the float rests at the bottom of the receiver and a part of a turn of the chain still remains on the drum, H. When these parts have been attached, water will be placed in the receiver to the depth of 4 or 5 inches, and a layer of kerosene about ¼-inch thick added to prevent evaporation. The spigot will then be opened, and closed when the flow of water has ceased.

The record sheet is arranged for use on the cylinder by first giving the sheet a cylindrical form, so that the punched holes in each end register over each other, then inserting the narrow metal strip through the holes so that the strip is on the outside of the sheet at only the center and ends. The strip must be inserted so that the top edge of the sheet will go next to the flange of the cylinder. Finally the sheet will be slipped endwise over the cylinder until the point of the metal strip is inserted in the slot in the flanged head of the cylinder. Of course, the overlapping ends of the rulings on the sheet should register with each other so that the diagonal lines come together.

When the record sheet has been put in place, the next step is to move the pen carriage, T, until it comes to rest against the stop or collar placed on the screw, N. The record sheet is to be started or changed at or near noon, and this time should be adhered to, if possible, for the length of the float chain has been so adjusted with respect to the zero level of the water in the receiver that when the pen is set on the sheet and the pen carriage placed against the stop,

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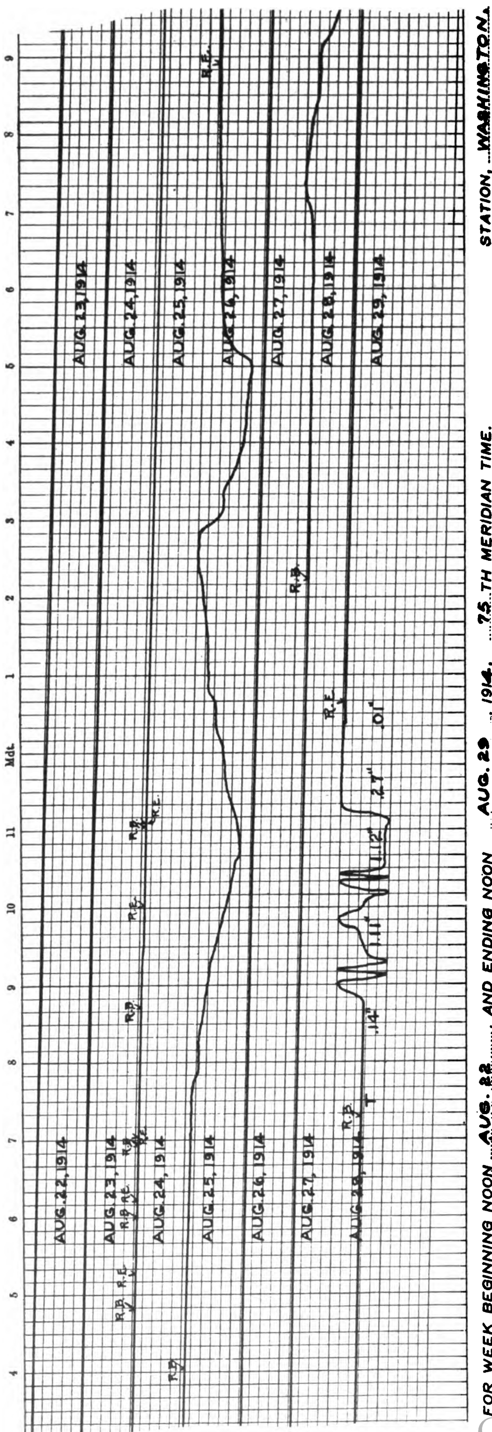

FIG. 4. Sample of portion of record sheet, reduced to about one-half size, showing actual record obtained at the Weather Bureau, Washington, D. C.

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the oscillations of the pen will fall between the heavy diagonal lines on the record sheet. The last operation is to adjust the pen to the correct time by rotating the cylinder on its axis in the proper direction, similar to the manner customarily used in setting the hands of a clock. The back lash can be taken up by effecting the final setting in a direction opposite to that in which the cylinder turns when moved by the clock.

Explanation of record.—Figure 4 shows a record sheet, the actual size of which is about 20 by 5¼ inches overall when trimmed at the right-hand end ready to be placed on the cylinder. The vertical graduations on the sheet are spaced nearly 0.13 of an inch apart and correspond to 10 minutes of time; and the diagonal lines are spaced 0.10 of an inch apart and correspond to 0.05 of an inch of rainfall.

The graduations are of such size as to permit the record to be easily read, as will be seen by examining the illustration, fig. 4. Take for example the rainfall recorded during the night of August 28, 1914. It will be noticed that "rain began" (RB) at 7.18 p. m., but from that time until 8.47 p. m. very little rain fell, as is evidenced by the line traced by the pen, which is very nearly parallel to the diagonal lines, but which still has an upward tendency. A trace (T), or an amount too small to measure, is therefore entered for the hour ending at 8 p. m. At 8.47 p. m., however, the record line makes a decided bend upward, passes across four-fifths of the space in which it is moving (amounting to 0.04 of an inch of rainfall), and thence across two additional diagonal lines; all of which totals to 0.14 of an inch of rain up to the point where the record line crosses the vertical 9 o'clock line. Between 9 and 10 o'clock the pen made four complete oscillations with an additional movement of slightly more than two divisions (corresponding to 0.11 inches), making a total of 1.11 inches for the hour. During the next hour another heavy downpour occurred, the gage recording 1.12 inches within 32 minutes, after which time until 11.05 p. m. no appreciable amount fell. The storm terminated with an additional heavy fall amounting to 0.27 of an inch within a short period ending at 11.10 p. m., the rain finally ceasing altogether at 12.40 a. m. (RE), after recording 0.01 of an inch between 12.20 and 12.22 a. m. The total amount of rainfall for the entire storm is therefore 2.65 inches. The performance of the gage in recording lighter rains is shown by the record for the period from 4.04 p. m., August 25, to 8.55 a. m., August 26.

The observer should be careful to record the times of beginning and ending of rain by eye observations, making a written memorandum of the actual time of occurrence to be transferred to the record sheet when removed from the cylinder. The beginning of rain should be indicated by the letters "RB" (rain began), the ending by "RE" (rain ended), and the actual time checked on the sheet.

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Insuring good record.—After operation of the gage has begun, there are several features to be considered in order that a good and continuous record may be insured, as follows:

1. The clock should be kept running to the exact time, as nearly as can be ascertained, and if adjustment becomes necessary, it will be accomplished in the usual manner by moving the small rod passing through the slot in the mounting plate, P, to the side marked S or F, to cause the clock to go slower or faster, respectively. If there is a time error, it should be noted on the record sheet when it is removed, and the corrections applied to the several beginnings and endings of rain.

2. If, for any reason, the pen has not made a complete record the total amount may be determined by noting the number of lateral throws made by the pen while the water is being drawn out to its original or zero level, preparatory to placing a new record sheet on the cylinder. The amount thus determined should be indicated on the sheet togethei with a brief note of explanation giving the times of occurrence of rainfall if practicable.

3. To avoid needless friction about every second week, and oftener in a dirty location, the horizontal bars and screws, I, U, and N should be rubbed off with an oily rag so that there remains a clean but *slightly* oiled surface over which the pen carriage slides. The long screw with the pin and carrier can easily be removed by backing off the pivot screw V, and all other parts should be thoroughly cleaned by use of kerosene or similar light oil. When cleaned these parts should be supplied with only the merest film of fine oil, and when replaced the pivot screw V should be set up so that there will be just a trifle of "end shake" to the screw N. Occasionally the pivot bearings in the mounting plate and post should be given a *little* clock oil. The clock being inclosed should need but little attention and will be cared for in the customary manner.

4. Under no circumstances will the gage be left out in freezing weather for if ice forms in the receiver or in the pipe leading thereto these parts are likely to be rendered unserviceable.

A FEW DON'TS.

Don't use force.

Don't forget that the gage is an *instrument* and that an *instrument* must be kept clean and handled carefully.

Don't use too much ink on the pen. In wet weather the ink absorbs water from the moisture in the air, and if some capacity has not been reserved for the increased volume the diluted ink will spill over and spoil the record at a time perhaps when it is the most valuable.

Don't allow the ink to be smeared on the pen arm.

Don't try to empty *all* the water out of the receiver. Only as much as will pass off through the spigot should be withdrawn.

Don't neglect to write your troubles to the Central Office of the Weather Bureau, Washington, D. C.

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U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., January 5, 1911.

Observers will familiarize themselves with the accompanying instructions relating to the care and manipulation of instruments employed for the measurement and registration of precipitation.

Additional details concerning the changing of record sheets, emptying gages, and full instructions for the care of register pens and the tabulation of records are given in Circular A, Instrument Division.

WILLIS L. MOORE,
Chief U. S. Weather Bureau.

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THE MEASUREMENT OF PRECIPITATION.

1. Rain, snow, hail, etc., are all included under the general designation, precipitation.

Rain.—The amount of rain falling at any time is measured on the basis of the depth of water which would accumulate on a level surface if all of it remained as it fell and none flowed or soaked away or was lost by evaporation.

Snow, hail, etc., are measured on the basis of the actual depth of the precipitation; also, and more definitely, by melting the snow or hail and then obtaining the equivalent depth of melted precipitation.

EXPOSURE OF GAGES.

2. The exposure of gages is a very important matter. The wind is the most serious disturbing cause in collecting precipitation. In blowing against the gage the eddies of wind formed at its top and about the mouth carry away rain, and especially snow, so that too little is caught. Snow is often blown out of a deep gage after once lodging therein.

a. Rain-gages in slightly different positions, if badly exposed, catch very different amounts of rainfall. Within a few yards of each other two gages may show a difference of 20 per cent in the rainfall in a heavy rain storm. The stronger the wind the greater the difference is apt to be. In a high location eddies of wind produced by walls of buildings divert rain that would otherwise fall in the gage. A gage near the edge of the roof, on the windward side of a building, shows less rainfall than one in the center of the roof. The vertical ascending current along the side of the wall extends slightly above the level of the roof, and part of the rain is carried away from the gage. In the center of a large, flat roof, at least 60 feet square, the rainfall collected by a gage does not differ materially from that collected at the level of the ground. A gage on a plane with a tight board fence 3 feet high around it at a distance of 3 feet will collect 6 per cent more rain than if there were no fence. These differences are due entirely to wind currents.

Full details of the causes and remedies for errors in the "catch" of gages and special devices for measuring precipitation are explained in the Appendix.

b. Since the value of the precipitation records depends so greatly upon proper exposure, particular care should be taken in selecting a place for the location of the gage, and every precaution should be

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taken to protect it from molestation. If possible, a position should be chosen in some open lot, unobstructed by large trees or buildings. Low bushes and fences, or walls that break the force of the wind in the vicinity of the gage, are beneficial, if at a distance not less than the height of the object. The gages should be exposed upon the roof of a building only when a better exposure is not available; and, when so located, the middle portion of a flat, unobstructed roof enclosed by parapet walls generally gives the best results.

3. In general, the rain and snow gages will be installed side by side, not nearer to each other than 3½ feet, center to center of gage. At stations where a recording rain-gage is in operation, a standard 8-inch gage for use as snow-gage will also be exposed. This gage may be used to check readings of rainfall in cases of emergency.

The instructions in paragraph 10 for the care of gages during freezing weather must be carefully observed.

Snowfall should be measured both as to depth of the layer of the snow itself, also the equivalent depth of the same layer supposing it reduced to the liquid state. Special methods and apparatus are required to effect these measurements in a satisfactory manner and the customary assumption that the water equivalent is one-tenth the snow layer is coarsely approximate.

DESCRIPTION OF STANDARD 8-INCH GAGE.

4. The gage consists of the following parts:

The receiver, *A*;
The overflow attachment, *B*;
The measuring tube, *C*;
The measuring stick.

The top cylindrical portion of the receiver, marked *a*, in fig. 1, is exactly 8 inches in diameter, inside, and is provided with a funnel-shaped bottom, which conducts rain falling into the receiver into the tall cylindrical measuring tube, *C*, the total height of which, inside, is exactly 20 inches. The diameter of this tube is much smaller than the large receiving tube, *a*, being only 2.53 inches. In consequence of this a small amount of rain falling into the receiver and flowing into *C* fills the latter to a depth greater than the actual rainfall in proportion as the area of the receiver is greater than the area of the measuring tube. In the standard gages of the Weather Bureau the depth of the rainfall, in accordance with this principle, is magnified just ten times. The receiver, *A*, has a sleeve, *d*, fig. 1, which slips over the tube, *C*. When the rainfall is very heavy the tube, *C*, may be filled to overflowing. In this case the excess of rainfall escapes between the sleeve, *d*, and the tube, *C*, and is retained in the large overflow attachment, *B*. The overflow has the same diameter as the collector, *B*, namely 8 inches and is used separately as a snow-gage in the manner explained in paragraph 10.

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5. The measuring stick is best made of a strip of straight-grained cedar 0.5 of an inch wide, 0.08 of an inch thick and 24 inches long, and graduated into inches and tenths of inches. Remembering that the actual depth of the rainfall is magnified ten times, as explained above, it is plain that if the water be 10 inches deep in the measuring tube, the actual rainfall must have been only 1 inch, or if the water in the tube be only one-tenth of an inch (or written as a decimal, 0.1 of an inch) deep, then the rainfall must have been only one one-hundredth of an inch (or written as a decimal, 0.01 of an inch).

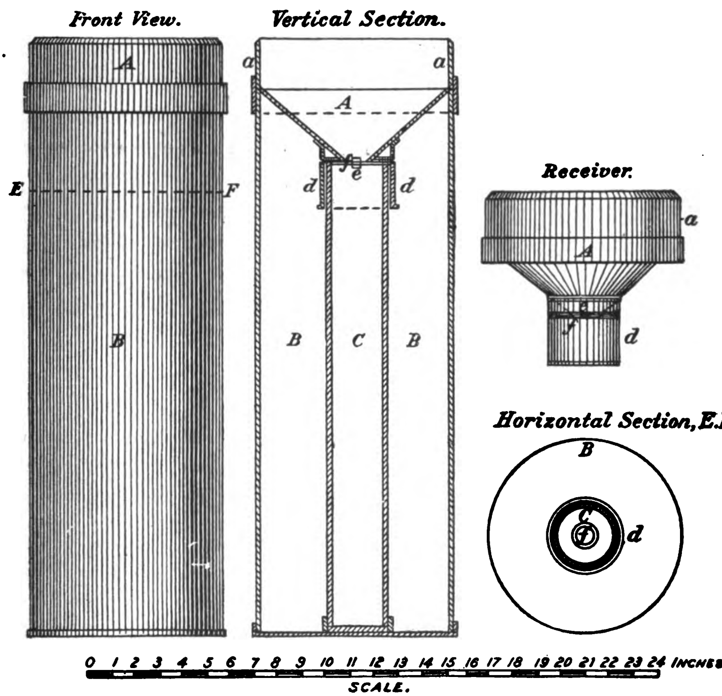

FIG. 1.—Rain-gage.

RAIN-GAGE SUPPORT.

6. *Iron tripod support.*—Fig. 2 illustrates the gage mounted in the standard iron tripod support, which, when erected upon a roof platform, is easily secured with screws through the feet. When a ground exposure is selected for the gage, it will be sufficient to drive down three substantial wooden stakes until about flush with the surface, and screw the feet of the tripod to them. If the ground is so hard that the tops of the stakes are bruised in pounding, it will be best to stop driving a few inches short of the surface, and saw off the projecting stakes to the proper level, then secure the screws firmly in the stakes.

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TO MEASURE RAINFALL AND SNOWFALL.

RAINFALL.

7. The depth of the water is measured by inserting the measuring stick into the gage through the small hole in the funnel. When the stick reaches the bottom of the measuring tube it should be held for one or two seconds, and then withdrawn and examined to see at which division of the graduation the top of the wet portion comes. The numbering of this division, *as stamped on the stick*, gives the actual depth of rainfall. In making out records and reports observers should *always use the decimal expressions*.

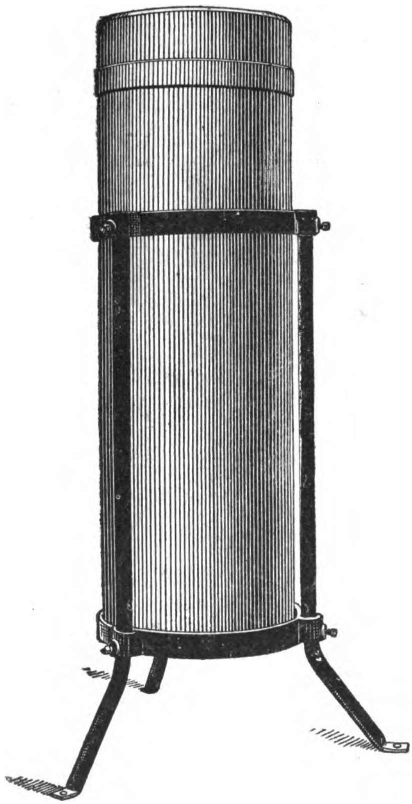

Fig. 2.—Rain-gage in iron tripod support.

8. After measuring and recording the precipitation, the top of the gage should be removed, the measuring tube emptied and drained, and the parts placed in position again. Observers should be careful to replace the measuring tube so that the bottom stands within the ring or bead in the middle of the bottom of the overflow, and in putting on the receiver to see that it passes over the measuring tube and rests squarely upon the overflow.

SNOWFALL.

9. When the amount of rain that has fallen more than fills the measuring tube, first carefully remove the receiver so as not to spill any of the water in the measuring tube, which should be exactly full. If some of the water has been spilled into the overflow a proper allowance for the amount should be made, or that remaining accurately measured with the stick, as already described. The tube it then carefully lifted out, so as not to spill any of the water into the overflow, emptied and drained. The water remaining in the overflow is now poured into the measuring tube, and the depth obtained in the usual way. Suppose this is found to be 0.47 inch rainfall; then, remembering that the measuring tube is just 20 inches high, the total rainfall will be 2 inches plus 0.47 of an inch = 2.47 inches. Or, in case some water was spilled from the measuring tube, the 0.47 inch should be added to the first measured amount to give the total rainfall.

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10. During the winter season, especially in those climates where the precipitation is nearly all in the form of snow, only the overflow attachment will be exposed in the support as a snow-gage, removing the receiver and measuring tube to the house. These parts can not be used for measuring snow, and even if rain should occur it would be very apt to freeze, and injure the measuring tube.

When the overfl v collector is unprotected from the wind its catch represents the true amount of snow only in the case of precipitation during calms or very light winds. On windy occasions the catch is often highly inaccurate and in the absence of special appliances such as described in the Appendix, the true quantity must be found, if possible, by measuring a section of the freshly fallen snow, cut out by forcing the overflow, mouth downward, through the layer and then slipping a thin board or sheet of metal underneath so as to separate and lift up the section of snow thus cut out.

Assuming that a representative quantity of snow has been obtained in the overflow a measurement may be secured by placing the vessel in a warm room until the snow has melted and then measuring the water in the measuring tube in the usual way.

The method just described is objectionable, owing to the time required and to the loss of the snow or water by evaporation. The following plan is much better: Take the overflow into the room and pour into it *one measuring tube full of water to the brim,* preferably warm. In cases of deep snowfall more water will be required. This will melt, or at least reduce to a fluid slush, a considerable amount of snow. The measuring tube should then be filled to the brim from the melted contents of the overflow and emptied; thereby discarding a quantity of water equal to that added. The remaining water in the overflow when measured in the tube then gives the actual depth of melted snow.

11. In addition to this measurement by the gage a measurement will be made of the actual depth in inches of the snow on the ground. Select a level place of some extent, where the drifting is least pronounced, and measure the snow in at least three places. The mean of these measurements will give the snowfall, which is to be entered in the column of the report headed "depth of snowfall in inches." Whenever it is impracticable to melt the snow as described in the preceding paragraph, one-tenth of this mean will give an approximate value, in water, for the snow which could not be melted. This value must be set down in the proper column of the report in precisely the same manner as rainfall or snow melted in the gage. After snowfall has once been measured the same snow should not be measured at subsequent observations. Any fresh snow, however, should be measured and recorded as it falls. For additional instructions for measuring snow see detailed description of methods and apparatus in Appendix.

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INSTRUCTIONS FOR USE OF SELF-RECORDING RAIN-GAGES.

DESCRIPTION OF THE TIPPING-BUCKET GAGE.

12. The gage comprises five principal parts, namely:

(1) The tripod support.
(2) The collector and inclosing case, which are in three pieces.
(3) The bucket frame.
(4) The tipping bucket.
(5) The measuring tube.

The collector is detachable from the remaining portions of the inclosing case, in order to facilitate access to all parts. This is also true of the middle section in some gages.

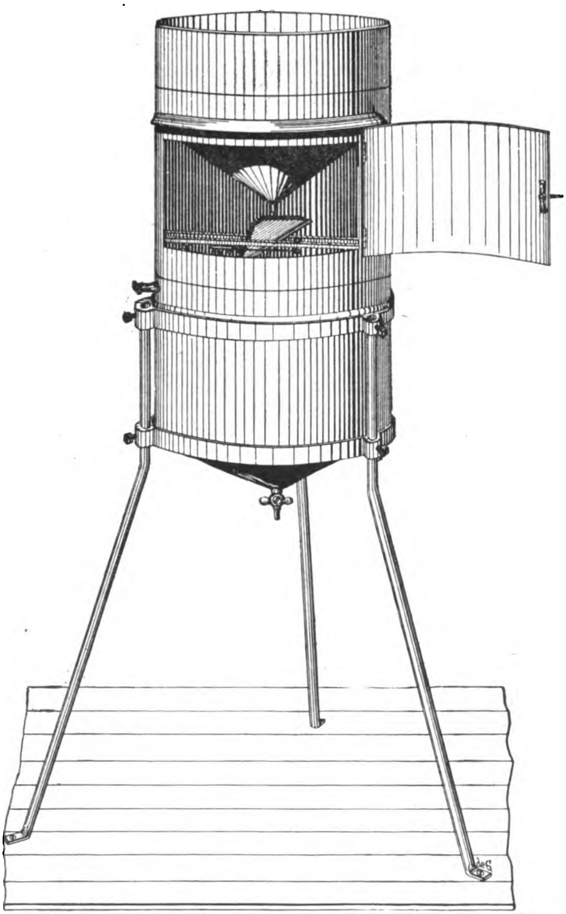

FIG. 3.—Tipping-bucket gage.

The top section, called the receiver or collector, is made of a sharp-edged brass rim, 12 inches in diameter, inside, and provided with a funnel-shaped bottom and a small tubulure at the center so that the water falling within the collector is conducted to a point directly over the center of the tipping-bucket bearings. The middle section is made of galvanized iron, with a hinged door. The lower section, or reservoir, is also of galvanized iron, and is provided with a brass stopcock at the bottom for emptying the gage of water.

13. The tipping bucket and a portion of the frame are shown in fig. 4. The bucket is mounted on a detachable brass frame carried on brackets within the inclosing case. A central partition, indicated by dotted lines in the drawing, divides the bucket into two equal compart-

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ments. The trunnions forming the axis upon which the bucket tips are placed below its center of gravity and the bucket is further supported in one or the other of two limiting positions by either of two blunt knife edge like stop pins located on the side of the bucket opposite that shown in the picture. In either position of the bucket one or the other of the compartments will receive and retain the water delivered through the funnel of the collector. The weight of the bucket and the position of its center of gravity have been so adjusted in relation to its supports that when one of the compartments has been charged with the quantity of water representing one one-hundredth of an inch of rain in the 12-inch gage, the bucket tips upon its bearings, emptying the water from the one compartment, and at the same moment presenting the other compartment to receive the

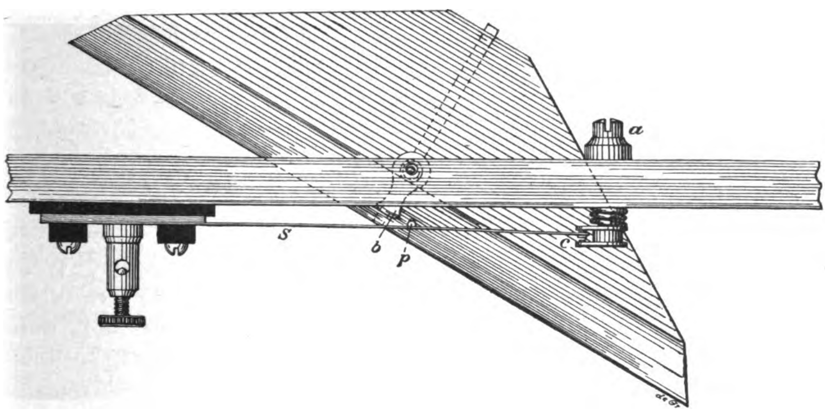

Fig. 4.—Tipping bucket and frame.

incoming water. The water thus delivered from the buckets is retained in the reservoir section for subsequent measurement in bulk.

AUTOMATIC REGISTRATION.

14. The automatic registration of each hundredth of an inch of rainfall, that is, each tip of the bucket, is effected by aid of the electrical circuit closer shown in fig. 4. Short sectors, *b*, are attached to each trunnion of the tipping bucket. When the bucket is at rest in either of its limiting positions the sectors stand near to, but not in contact with, a pair of circuit-closing springs of which the insulated one is shown at *S*.

In the act of tipping, after the bucket has moved a little, the sectors, *b*, make contact with the springs and rub over them during the greater part of the subsequent motion. This effectually closes the electric circuit which is formed between the whole metallic framework, including the bucket, and the insulated spring, *S*. During the last portion of the tip of the bucket the sector, *b*, slips off and moves a small distance

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away from the springs, thus opening the electric circuit, and also leaving the bucket perfectly free to tip with the next hundredth of an inch of rain.

15. The contact of the sectors, *b*, with the springs will generally close the electric circuit, nevertheless, when the contact spring, *S*, is deflected by the passage of the sector, *b*, the platinum-tipped end at *c* makes contact with the platinum point attached to the adjustable post, *a*, thus providing a second simultaneous independent closure of the electric circuit.

16. *Adjustment of contact spring.*—The contact spring is in proper adjustment when the end, *c*, rests against the insulated point on the adjusting screw, *a*, and when, upon tipping the bucket, the sectors, *b*, rub rather easily over the springs; at the same time the platinum tip at *c* must make contact with the platinum point on the adjustable screw, *a*. If *p* is but slightly touched by the sector, *b*, or is missed entirely, or if *p* must be pushed aside considerably and presses hard against the sector while passing, these defects may, in general, be remedied by properly turning the screw, *a*. In some cases it may be necessary to bend the spring slightly as well as to adjust the screw, *a*. Observers are particularly cautioned to remedy faulty adjustments of the contact springs. All instruments are in perfect adjustment when sent out, and little or no occasion should arise for readjustment if the mechanisms are properly cared for. The holes in which the axis of the bucket rests are intentionally about twice the diameter of the pinions in order to diminish the friction to the minimum. One of the holes is slotted on top to permit the removal of the bucket for cleaning or other purpose.

17. *Double contact springs.*—To insure electrical connection during tipping, buckets are provided with two spring contacts similar to the one described above, except that the end and the contact at "*c*" are omitted in some cases. The second spring with its corresponding sector is placed on the opposite side of the bucket from that shown in fig. 4.

18. *Back-tipping, or rebounding, of bucket.*—If the bucket is placed in the frame with the stop-pins on the front side, that is, so as to strike on the side of the supporting frame having the slotted opening and binding posts, it will be found that during rainfall the recoil of the bucket, on tipping, will frequently cause it to rebound and produce two steps of the recording pen in quick succession. These are apparent on the record and are due to the faulty position of the bucket which must be placed with the stop-pins on the rear side of the frame, in which position there is scarcely any rebound.

19. *Instructions for mounting.*—When shipped, the brass frame carrying the tipping bucket is generally separate from the gage, and the tripod support is in parts. The manner of putting the latter together will be readily understood from a view of the completed tripod

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in fig. 3. The bucket frame is readily placed in position within the inclosing case and secured to the brackets. The binding posts on the frame should come on the side nearest the door in the middle section.

20. *Accuracy of measurement.*—The accuracy with which any given bucket will deliver a certain quantity of water at each tip has been experimentally investigated. Although every precaution has been taken to secure the greatest accuracy in the adjustment of the buckets, yet, owing to unavoidable irregularities in the action of the water in the buckets, and to the fact that a very small discrepancy in the volume of a single tip may become important in the total volume of one or two hundred tips, it will often be found that the total volume shown by the automatic record fails to agree with the actual volume of water retained in the reservoir.

This may result from one or more of several unavoidable causes. The buckets have been adjusted to deliver the proper volume of water for slow and moderate rates of rainfall, such as most frequently prevail. During heavy showers, when, for example, rain is falling at the rate of 5 or 6 inches per hour, each bucket will be filled to the tipping point in from six to seven seconds, or thereabouts. Inasmuch as a very small but nevertheless perceptible amount of time is required for the bucket to tip far enough to cut off the inflow of water, it is obvious that during such rapid rainfall an appreciable quantity of water will flow into the bucket after it has begun to tip. Accurate measurements made at this office have shown that the time required by the standard buckets to tip from the starting point to a point where the inflow of water is cut off is about three-tenths of a second. It therefore follows that when the water is flowing into the bucket at a rapid rate—such, for example, as will fill the bucket to the tipping point in six seconds—then during the three-tenths of a second occupied in tipping, water will continue to flow into the bucket, and the excess thus delivered will be about one-twentieth of the whole amount; that is, an inch of rainfall will cause the bucket to tip only about 95 times, whereas the same amount of rain at a slow rate would cause the bucket to tip 100 times. The discrepancy from this cause has been reduced as much as possible, but it can not be entirely eliminated in the case of small buckets—such, for example, as will make 100 tips per inch of rainfall.

It will be found also that the different hygroscopic conditions of the metal surfaces cause the water to wet the buckets in a different manner on different occasions. This will lead to a slight difference in the volume of water delivered per tip of the bucket.

After being thoroughly wetted with more or less dirty rain water, which afterwards dries away, a sediment is left upon the metal surfaces; as this alters their hygroscopic character, it is desirable that at least the inside surfaces of the buckets be kept as clean as possible. The bucket should be removed from the supporting frame from time

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to time as may be required by the atmospheric conditions at the several stations, and the compartments thoroughly cleaned. No deposits of dirt should be allowed to accumulate in the bearings of the axis or about the small pinions of the bucket. Special pains must be taken to avoid bending trunnions, as slight changes here will have an important effect in changing the volume of water delivered per tip.

21. *Corrosion.*—The most serious cause of error in the amount of water delivered per tip has been found to be due to the effects of dust and *corrosion on the frame and stop-pins of the bucket.* It is absolutely necessary that the stop-pins and points on the frame where the pins strike be frequently cleaned. Of course the bucket and frame should be kept clean elsewhere also, but as soon as the pins and points of contact on the frame become dirty a slight adhesion is established between the two when in contact. When the dirt at these points becomes wet or damp, as it does during long rains, the adhesion becomes aggravated and more water must enter the bucket in order to overcome the sticking at the stop-pins, thus causing a more or less serious deficiency of record.

22. *Effect of faulty leveling.*—If the brass frame which carries the bucket is not properly leveled, one of the compartments will deliver a greater and the other compartment a less volume of water, per tip, than the normal amount, although the average of the two will still remain very nearly the normal volume. While the errors resulting from small defects of level are not serious, it is desirable that some pains be taken when installing the gage to make the frame upon which the bucket is mounted as nearly level as practicable.

23. *Recording mechanism.*—The apparatus designed to record the tips of the bucket is attached to the so-called triple register. The record sheet upon this instrument moves at a relatively rapid rate. Nevertheless, in order to render the registration of the most rapid rates of rainfall legible, the recording pen traces its record in a zigzag line of steps, each step represents a hundredth of an inch of rain, and one complete zigzag comprises ten steps. In the majority of cases the individual steps are perfectly legible, but in records of very rapid rates each individual step can not always be discerned. The points of the zigzag, however, are separated by ten tips or steps and are distinguishable under even the most rapid rates.

24. The recording pen on the zigzag marker is easily adjustable laterally, and observers must arrange for the entire zigzag trace to fall within the available space on the record sheet so as not to encroach upon the anemometer record.

25. When a record sheet is to be changed, the whole pen arm is lifted a short distance upon the staff supporting it and turned to one side, thus providing free access to the cylinder. In replacing the pen, care must be exercised to place the steel pin within the groove of the cam wheel, which produces the zigzag motion.

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When the pen of the rainfall magnet has been lifted from the sheet temporarily, care should be exercised not to disturb or move the armature of the magnet, or to make any change in the position of the ratchet cam, except such as results from the closure of the electric circuit. If these parts are not disturbed, the pen, when replaced, will continue its trace of steps in proper sequence relative to the original trace. By this precaution the pen may be lifted from the sheet for a short time while record is being made, and although a few steps of the cam may be taken during the interruption of the record and of which no corresponding trace is made, yet an examination of the record with respect to the complete zigzag will show the number of steps less than ten that may have been lost.

26. *Check readings.*—Owing to unavoidable sources of errors in the volume of water delivered per tip of the bucket under various circumstances already explained, it is necessary that when rain has been recorded the total volume of water in the gage shall be checked with the automatic record, and for this purpose the observer will enter upon the record sheet, when changed, the "stick measurement" of the gage.

27. *Check readings, how made.*—To ascertain the total volume of water in the gage the water retained in the reservoir will be drawn off into the brass measuring tube, with which each gage is provided, and the amount measured in hundredths of an inch by stick in the usual way.

28. Observers are cautioned against using the small brass measuring tube belonging to the ordinary (8-inch) gage for measuring the rainfall collected in the tipping bucket (12-inch) gage. If, from necessity, the small tube is used, the apparent depth of rainfall measured in the smaller tube must be divided by 2.25, in order to ascertain the true depth of rainfall in the 12-inch gage.

29. *Precautions against freezing.*—As the tipping-bucket gage does not record snow or similar precipitation in the solid form, observers will use all necessary precaution to prevent the collection of partly melted precipitation which may subsequently freeze and injure buckets, or otherwise make the gage unserviceable. When such injuries are probable, the cylindrical portions of the gage should be removed to the office.

APPENDIX.

INFORMATION AND SUGGESTIONS FOR COLLECTING AND MEASURING PRECIPITATION ESPECIALLY IN REGIONS OF HEAVY SNOWFALL.

The chief object of the following discussion is to enlist the intelligent interest of section directors, observers, and others in the problem of collecting and measuring precipitation and to invite their cooperation in perfecting methods and apparatus with which better observations, especially of snowfall, may be obtained.

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We shall therefore give briefly the fundamental principles of the problem and mention the difficulties that lie in the way of its solution; then describe certain methods and apparatus with which, according to numerous experiments that have already been made, useful results seem likely to be realized. With this statement of the case before them officials and observers may be prompted to indicate further improvements and offer new and better solutions suggested by their large experience with field conditions.

30. *Precipitation defined.*—In a primary and restricted sense the word "precipitation," means only rain, snow, hail, or even fog, if in measurable quantities, that condenses from the aqueous vapor in the atmosphere and falls upon the general surface of the earth near by.

Little confusion arises in the application of the word in the case of heavy forms of precipitation, such as rain and hail, practically all of which remains at the point of falling. Light snow flakes, however, are often not only prevented by the wind from permanently resting at the place where they first reach the ground, but even after actual precipitation has ceased, they may be drifted about or caught up into the air to fall again at distant points like new precipitation. It thus occurs in hilly and mountainous regions that the wind-swept slopes and ridges are often robbed of their legitimate quota of the normal snowfall, while the sheltered slopes, gorges, valleys, and canyons ultimately get an excess over that obtained directly from condensation.

31. From the point of view of aerophysics, the depleted snow on the wind-swept ridges and the excessive snow in the sheltered places are both false representations of the true precipitation—that is, the atmospheric condensation—for the region in question. On the other hand, the unequal distribution of the snow in the cases under consideration is a normal feature of the locality, being repeated in a general way, season after season and year after year. From the climatological point of view, therefore, the snow on the ground in any of these cases literally belongs where it is found, and is properly called the precipitation for the place, although it may represent either more or less than the actual condensation of atmospheric moisture appropriate to the vicinity.

As a matter of pure climatology, therefore, it is proper simply to measure the snowfall actually found at a station, without asking whether or not it formed there directly from atmospheric condensation.

32. The problems of hydrology, of irrigation, and the conservation of water resources, demand, however, more specific observation and measurement of precipitation. For these needs there must be known not only the true amount of water normally available from atmospheric condensation within a given region or watershed, but also the amount stored in local beds and drifts of snow that will ultimately melt and flow into the streams and rivers.

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33. The causes leading to the condensation of atmospheric moisture are themselves extremely varied and complex, being connected in many cases directly with great cyclonic disturbances, and in others with purely local conditions influenced by topographic features. Consequently great local variations in precipitation are to be expected in nearly all cases.

LOCATION AND SELECTION OF STATIONS.

34. Since precipitation may thus be so irregularly distributed over relatively limited districts, its complete observation, especially in regions of great topographic diversity, is possible only by the aid of a very large number of stations uniformly distributed. The averages and variations of many observations thus obtained no doubt give a close approximation to the true facts of precipitation.

35. It will be impossible, at least for a long time to come, to establish a sufficiently large number of stations in some districts to give all the precipitation data desired, especially is this true of the mountainous regions of the West. Efforts must, therefore, be made to ascertain the best methods to employ at the small number of stations from which observations may at present be obtained.

36. In the great majority of cases stations are necessarily located in or near cities, towns, and villages. As these are found mostly in the valleys or sheltered slopes, rather than on ridges and exposed terraces, it follows that observations from stations thus located will tend to show *more than the true precipitation for the region*, the excess being caused by the indrifting of the snow from the wind-swept slopes and ridges often not far away. The record of snowfall will be nearly normal from stations located in regions of small wind movement, on extensive plains, in broad, open valleys, or at long distances from prominent topographic features. The drifting of snow that ordinarily occurs in such localities is confined to relatively narrow limits close to the ground, and, on the average, about as much snow is blown away from a given surface as is drifted to it from other points.

37. Every satisfactory study and discussion of snowfall data must, therefore, include a consideration of the exposure and environment of the *individual stations*. It must be recognized that normal amounts of snowfall are to be expected only from stations situated in wide stretches of open country, that too much snow will be reported from stations in the smaller sheltered valleys, and that too little snow to represent the average fall in the region is likely to be reported from stations located upon exposed slopes and ridges.

38. These conclusions presuppose that the measurement of the actual precipitation at these stations can be made with equal accuracy. This, however, can not be done, and the student of precipitation

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records must be on his guard, not only against the anomalies in distribution due to nature herself, but also against those introduced by faulty observations.

The further discussion of the measurement of precipitation will be materially aided by recognizing that observational work of this character subdivides naturally into certain classes, as follows:

CLASSIFICATION OF RAIN AND SNOWFALL OBSERVATIONS.

I. Measurements of rainfall: Observations made daily or after precipitation. Require only rain-gages of well-known type.

II. Measurements of snowfall: Observations made daily or after precipitation. Can often be measured on the ground, but accurate results require special equipment for collecting the snow.

III. Measurements of the depth and water content of the whole layer of snow on the ground. Require special equipment. May be reported daily or at longer intervals, and at specific times, as just before the thawing season.

IV. Seasonal and semiseasonal measurements: These comprise other classes where conditions preclude frequent measurements.

With this classification in mind, methods and apparatus will next be considered.

METHOD AND APPARATUS.

GENERAL CONSIDERATIONS.

39. Throughout more than half a century, numerous experiments have been made in collecting and measuring precipitation, and for a number of years the causes of errors have been pretty thoroughly understood, and the methods by which rainfall, at least, may be properly collected for measurement have been frequently demonstrated. The pages of the Monthly Weather Review for past years contain numerous notes and articles bearing upon the problem, and the essential points have been brought out repeatedly. Numerous communications have also been received by the Weather Bureau, describing and recommending new methods and apparatus for the collection and measurement of snowfall in the West. Many of these have contained novel and helpful suggestions, but it is apparent that with one or two exceptions the writers were not familiar with the main difficulties of the problem; at least they disregarded the useful lessons to be drawn from older experiments.

40. Professor Abbe has given a short summary of probably the most important parts of the literature of the subject in the article in Appendix 1, Bulletin No. 7, Forestry Division, Department of Agriculture, 1893, partly reprinted in the Monthly Weather Review, Volume 27, 1899, page 464. It is recommended that those who are advocating

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new methods and apparatus for the collection and measurement of precipitation over the thinly populated regions of the West make as full a study as possible of the literature of the subject.

41. It may be summarized here briefly that it has been demonstrated over and over again that *the catch in unprotected gages in the wind is always deficient;* also, that *certain forms of wind shields, or protecting barriers, such as fences, serve to ward off almost entirely the ill effects of the wind in the case of rainfall.* The benefits from shields or fences in the case of *snowfall* have not been sufficiently demonstrated, and since all the difficulties are aggravated in the case of snowfall, it is doubtful whether any available form of collector can be relied upon to catch the true amounts of snow in all its forms and under windy conditions.

42. The following general propositions are either sufficiently obvious or may be formulated as direct results of trustworthy studies and experiments.

1. In calms and very light winds all gages of reasonable form and dimensions and in similar locations catch sensibly true and equal depths of precipitation.
2. In moderate, brisk, and high winds the catch of gages not screened or protected becomes more and more deficient with the increase in the force of the wind.
3. The deficit in catch due to wind is greater for snow than for rain.
4. In collecting *rain*, the deficit in catch, even in strong winds, can be reduced to a relatively small percentage by the use of appropriate wind shields, fences, and other protective barriers, such as have been successfully employed by Nipher, Hellman, and others.
5. Additional careful experimentation is needed to perfect and improve wind shields and to demonstrate that gages so protected collect snow satisfactorily on windy occasions.

43. It follows from the foregoing principles, that the "catch" of any of the gages, bins, or elevated pipes thus far recommended for use, is certain to be deficient both for rain and for snow during periods of moderate to high winds. Indeed, recent observations on snowfall have shown this to be true with bins and gages, even when they are set up in the deep glades of the woods, supposedly well-sheltered from the wind. Observations show that cubical bins elevated several feet above the ground constitute such a large obstacle to the free movement of the air, that even moderate winds are quite adequate to cause deficits in the "catch" of the light snowflakes.

44. It is important that the work of the Weather Bureau in collecting precipitation data, especially from the great watersheds of the West, should be carried out by apparatus and methods that are in harmony with the well-established principles governing the collection and measurement of precipitation.

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45. The primary problem presented is, first, to "catch" the snow. Its subsequent conservation and measurement is not a very difficult matter.

A proposal to catch the snow by some new method or device involves the obligation or necessity of demonstrating that the "catch" correctly represents the desired precipitation. Especially must the truth of such a claim be demonstrated if, guided by well-established principles, we are led to believe the catch of the proposed collector is likely to be deficient on windy occasions.

46. In view of the difficulties enumerated, the question naturally arises, how can the true amount of precipitation, especially when in the form of snow, be determined in any given case? We shall endeavor to answer this important question with some fullness.

47. *The absolute measurement of rainfall.*—It is generally conceded that the true catch of rainfall is obtained by the so-called pit gage; that is, a sunken collector, with its mouth elevated above the ground only far enough to prevent insplashing to any serious extent and set in the middle of a large open level field. Such a gage, however, easily becomes fouled with leaves and litter, and consequently its use is objectionable except as a standard of reference in experimental investigations. A better disposition is secured by forming a shallow pit, a foot or so deep, with the earth thrown up in a circular rim 6 or 8 feet in diameter. The collector is placed at the center of the depression with its mouth about level with, or a little below, the rim of the pit. Such a gage is so effectually sheltered from the wind that it collects the same quantity of rain as falls upon an equal area of the ground near by.

48. Nipher demonstrated in 1878 that almost or quite the true catch of rainfall could be collected in ordinary rain-gages by surrounding them with a trumpet-shaped shield of sheet metal terminated in an annular rim of copper wire gauze, 20 gage, mesh 8 wires per inch, to prevent insplashing. This device so far minimized the ill effects of the wind, that one of these shielded gages on a pole 18 feet above the tower of the university and 118 feet above the ground, collected the same amount of rainfall as a shielded gage on the ground. Hellmann and others have also found the Nipher screen useful, and have secured equally satisfactory results by the use of a fence or wind brake around the top of the gage, at a distance from it equal to the height of the gage, and at an angular elevation above the gage of about 20 to 30 degrees. These devices deflect and check the force of the wind at the mouth of the gage to such an extent that the raindrops can enter the gage in a normal manner, and a true catch be obtained.

49. It seems appropriate at this point to say that, while the Weather Bureau is compelled to expose rain-gages upon the roofs of lofty buildings in large cities, the catch of rainfall thus obtained is

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often quite satisfactory. This is accomplished by taking advantage of the sheltering and protecting influences afforded by large parapet walls, which are generally to be found around flat-topped office buildings. Shields and guards upon the gages themselves in these cases are not so effectual, since the distribution of the rain over the roof is quite irregular. The whole building may be regarded as a huge, lofty rain-gage. If shields and fences could be put around the building itself, a true catch might be secured, but in the absence of these, a gage located in the middle of the roof, especially if it is surrounded by parapet walls three or four feet high, collects nearly the true amount of rain. Roof exposures are accepted by the Weather Bureau as an unvoidable necessity at its stations in the centers of large cities where better exposures are impossible. Ground exposures obtain wherever conditions permit, as for example in the smaller cities and at stations of cooperative and special rainfall observers.

50. From what has been stated it appears that the pit-gage is probably the ultimate standard for the collection of rainfall and that a nearly true catch may also be obtained by the use of properly shielded gages.

51. *The absolute measurement of snowfall.*—Obviously the pit-gage is almost useless for the collection and measurement of snowfall in many cases, and the efficacy of wind shields or fences in overcoming the effects of high winds is limited, or has not as yet been sufficiently demonstrated. As regards the latter the most direct test known to the writer is afforded by the recent observations of Billwiller, given in Meteorologische Zeitschrift, May, 1910. A shielded gage something like the Nipher pattern was installed near the ordinary unshielded gage at a hospice on the Gotthard in the Alps. Satisfactory rainfall and snowfall measurements had never been made at this place in preceding years on account of high winds. During 1908 and 1909 the catch of snow in the shielded gage was 50 per cent greater than in the ordinary gage, even in light winds. With high winds the catch averaged about 100 per cent greater, that is, the shielded gage collected twice as much snow as the customary gage.

52. In view of the difficulties and inaccuracies attendant upon *collecting* snow for measurement, the Weather Bureau has long required its observers to *measure the snow upon the ground* in one or more selected spots where experienced judgment indicates that a normal and representative depth of snowfall is to be found. Even on windy occasions the snow may be found in uniform beds in thoroughly sheltered places, where the force of the wind in proximity to the ground is effectually checked and reduced. Perhaps the best illustrations of this are to be found in the partly wooded parks with small open places, or more particularly in the small clearings in deep woods with sufficient undergrowth to prevent any appreciable underflow of wind. Measurements

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of newly fallen snow on the ground in such places probably gives the best representation obtainable of the true precipitation in the vicinity at the time.

53. Since one object now prominently in view is to develop and perfect devices by which the snow may be accurately collected at any time and in any place, it is of paramount importance that some independent and standard method be employed by which the actual snowfall in given cases may be ascertained, and by comparison therewith determine the errors, if any, of the proposed collectors. For this purpose the writer is firmly convinced there is nothing better than personal measurements of the snow on the ground by experienced and careful observers, especially when aided by a few simple facilities for the purpose. It should be borne in mind, however, that this method is recommended only as an ultimate standard for reference, to be used for comparative purposes under favorable conditions, and to demonstrate the reliability of gages.

54. There are many cases when ground measurements cease to be accurate, or can not properly be employed for comparisons. Some of these may be mentioned:

1. When snow and rain are mixed or alternate.
2. When melting accompanies the snowfall, or otherwise affects the results.
3. When snow is already upon the ground.
4. When the amount of fall is very small.
5. When drifting is very bad.
6. When the snow is blown about badly after the storm and before measurements are made.

55. There are many other cases, however, especially in regions of heavy snowfall, when the measurement of the snow upon the ground at selected places under favorable conditions is the best method known for determining the true amount of precipitation. The method may then be properly used to demonstrate whether or not the snow can be correctly collected. This is particularly true when the depth of the fall has been considerable and when measurements are made shortly after the storm. The ease with which several independent measurements can be made in different places permits of computing a mean result of great accuracy. The simple measurement of the depth of snow is, however, not sufficient. The water equivalent must also be accurately determined as will be indicated later.

56. The method of ground measurements in accordance with details which will be given presently, and subject to the limitations just indicated, may therefore be regarded as a standard method of making snowfall measurements.

Having indicated the general principles for the absolute measure- ›nt of precipitation, the details as to practicable methods and appa- ›us now require consideration.

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DETAILED DESCRIPTIONS.

OBSERVATIONS OF CLASS I.

57. The standard rain-gage used by the Weather Bureau has already been fully described in paragraph 4, and consequently needs only to be mentioned here.

Such a gage can not be used for snowfall, but any form of shielded or protected gage that may be demonstrated to successfully catch the snow is equally suited for the collection of rainfall, and the accuracy of rainfall observations would doubtless be increased by its use.

OBSERVATIONS OF CLASS II.

58. *Measurement of snow on the ground.*—The method now to be described was proposed by the writer in 1908, but up to the present time has not been put into systematic use. The "density-of-the-snow-gage" required for the purpose was sent to a number of stations late in the winter of 1909–10. The instructions then furnished for its use are given below, with some additions and alterations.

59. The method of measurement comprises two distinct operations: (1) The measurement of the *depth* of the snow layer; and (2) the determination of the *density* of the snow.

The apparatus (fig. 5) consists of a substantial measuring stick, with a scale of subdivisions to inches and tenths, and a special spring balance for determining the density of a measured volume of snow by weighing it in a pail provided for the purpose.

60. *Measurement of depth of snowfall.*—Existing instructions, which require the observer to measure the depth of snowfall at one or more points representative of the normal depth, will continue in force. There are two general conditions under which measurements must be made, however, which call for consideration.

The measurement of snow which has fallen on bare ground; here it is necessary only to measure the depth to the surface of the ground. Under such circumstances observers will determine with the aid of the measuring stick the depth at one or more places in open fields or on level surfaces where the layer has not been seriously disturbed or modified by drifting.

61. The measurement of snow that has fallen on a previous layer; under these more difficult conditions measurements can sometimes be made on surfaces from which the previous layer of snow has been removed before the second fall began. In other cases, especially in cities, it is often possible to distinguish the surface of the previous layer by its discoloration from soot or dirt, or the formation of a crust through sleeting or freezing. The line of demarcation between the old and the new snow is often apparent to the eye by slight differences of texture or density, and which are revealed by cutting down

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through the bed of snow so as to expose a definite vertical section. Under such circumstances measurements of the depth of newly fallen snow may be made by ordinary methods that will readily suggest themselves to the observer.

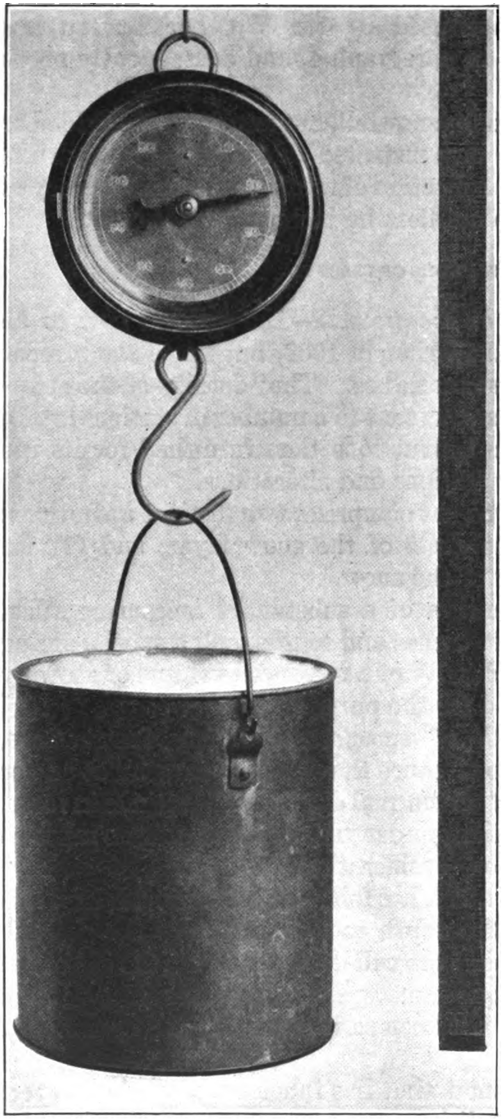

FIG. 5.—Apparatus for measuring snowfall by depth and density.

Efforts to provide a floor or platform that shall be swept clear before a new fall of snow occurs can not be generally successful because of drifting, and its weight precludes supporting such a floor upon the snow itself. Further complications arise in the matter of temperature differences between the floor and snow in the sunshine.

62. *The snow mat.*—This simple device will often aid in marking the surface between the old and new snow. It consists of a small square, 28 inches by 28 inches, of white duck, medium weight, neatly hemmed and provided with small triangular pockets at each corner. Two slats of wood, 2½ inches wide by ¼ inch thick, forced into diagonally opposite corner pockets and secured to each other where they cross, serve to maintain the mat taut and flat. Two or more short pegs, projecting downward from the slats, may be provided if necessary to better secure the mat against displacement by the wind.

63. When snow is already on the ground, the mat is simply laid upon the surface in some favorable location. A few yards of small

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cord tied to the mat and to some slender stake nearby prevents the possible loss of the mat, and serves to indicate its location when covered with snow.

The lightness of such a mat permits the soft snow to support it, so as to remain sensibly even with the surface of the old snow. Its color and material favor equality of snow and mat temperatures under conditions of sunshine, and thus lessen the chances of partial melting. Since the surfaces of the mat and snow so nearly coincide, drifting is of slight consequence, except in very light snowfalls.

64. When a measurement is to be made, the position of the mat must first be located by the cord, and a little of the snow cleared so as to expose a small portion of the mat. The depth of the snow over the mat can then be accurately measured.

The object in all the cases considered is simply to measure the *depth* of the normal layer of snow since last observation by one or more of the several methods described.

65. *Measurement of the density of snow.*—Many methods are available for the measurement of the density of the snow, but probably none is so convenient or reliable as that of carefully weighing an accurately measured volume. This may be done expeditiously and with sufficient accuracy through the use of the spring balance and copper receptacle.

66. The copper pail is to be filled with snow that has fallen during the period covered by the observation. While it is desirable that the sample of snow be taken near the point at which the depth is measured, yet this is not necessary, provided the measurements of depth and the sample snow represent nearly enough the average state of the precipitation. The bucket should be cold before filling, so that melting and subsequent freezing may be avoided. Carefully fill the bucket, so that the density of the snow placed therein may be the same as that upon the ground; the snow must not be compressed nor must voids be left in the bucket. Fill evenly to the brim and hang the bucket upon the balance. The reading of the index hand gives the *density of the snow*. For example, if the index stands at .18 on the dial, it means that the density of the snow is .18 that of water.

67. If not much encrusted, and when the depth of the snow permits, a sample of normal density may be obtained by pressing the inverted bucket slowly down into the layer of snow until its bottom is just level with the surface. Then remove the snow from beside the bucket and slip a hand-shovel, or piece of thin metal, under the mouth, thus securing perhaps as nearly as may be a sample of unaltered density.

68. When the character of the precipitation changes during deep falls of snow, the density will not be the same at different depths, and samples taken in the manner just explained will not show the average density of the whole layer. In such cases, perhaps the best way to

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collect the sample is to cut straight down through the snow layer with a small hand-shovel, or plate of sheet metal, so as to expose a vertical section. Then scrape off and place in the bucket small quantities from the whole face of the section, thus gradually filling it with a sample of average density. It seems better to add the snow to the bucket successively, in small quantities, rather than try to fill it with a few large portions.

69. When the snow is wet, or if for other reasons it seems difficult to secure a good sample, the observer should make several independent measurements. The variation in the results thus obtained will indicate the probable error of the measurement, and the mean density so found can hardly be seriously in error.

70. *Water equivalent of snowfall.*—Having ascertained the density of the snow, the water equivalent is obtained by multiplying the depth of the layer by the density. For example: Suppose the depth measured to have been 8 inches and that the density was found to have been .18, then the depth of the water represented by the snow would be $8 \times .18 = 1.44$ inch.

71. Thus far the measurements of depth and density have been considered only in relation to the *snow since last observation*. Obviously the method and apparatus may be employed to measure the whole snow layer, the depth of which in a given spot can in general be easily determined. The density, however, may vary considerably from point to point, and observations of this kind can be made better by the use of the snow tubes described later on.

72. *Shielded rain and snow-gage.*—Snow in all its forms can be successfully measured on all occasions only by first *collecting* a certain portion. The type of gage we shall now consider aims to correctly collect either rain or snow, and its design is believed to harmonize as nearly as possible with well-established principles.

73. A gage to collect snowfall must necessarily be elevated several feet or more above the ground to escape the surface drifting that often occurs. This elevation may need to be as much as 20 to 30 feet in wind-swept localities and at stations where the accumulated depth of snow during the winter is very great, although it is not to be understood that in hilly locations the gage must be elevated sufficiently to escape the indrifting of snow that comes from wind-swept ridges at considerable distance.

As stated in paragraph 31, climatologically, such snow belongs where it is found, and our gage should collect it.

74. Among the numerous plans that have been submitted for catching and conserving rain and snow, the advantage of making measurements by weighing has seemingly been quite overlooked. Several methods for melting and liquefying the snow collected have been recommended, for example, by the use of chemicals and brines, or by

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placing storage tanks below the frost line. These provisions are mostly unnecessary. The catch of a gage can be conserved either as snow or rain and measured with accuracy by weighing. The possible complications from the freezing of liquid contents are probably easier to overcome than are the difficulties encountered in the use of melting methods.

75. The shielded gage for ground exposure is shown in fig. 6. The collector is a tall cylindrical can, 40 inches deep by 10.85 inches inside diameter. Three inches of rain, or its equivalent, caught in a receptacle of this diameter, weighs 10 pounds. A spring balance of regular manufacture, with the dial altered to show rainfall in inches and hundredths, is easily obtained and employed to determine the contents of the gage. The capacity of the collector is adequate to contain any snowfall likely to occur at most stations between regular hours of observation, and can, of course, be increased if special conditions require.

76. A double arrangement of wind shields surrounds the mouth of the gage. On the outside is a large Nipher trumpet-shaped shield of galvanized sheet iron, arranged in octagonal form to simplify construction, and to reduce cost. Inside the trumpet shield is a fence shield consisting of four sheets of iron, 12 inches wide, spanning the space between the corner posts. The upper edges of the shields stand above the rim of the gage by from 20 to 30 degrees angular measure.

At the top the collector is centered and secured in place by a guard ring carried on the supports. At the bottom the can rests upon a central support, which can be raised and lowered for placing and removing the collector.

77. For measurements the collector is hung upon an appropriate spring balance swung from an arm of the support. The dial readings give the rainfall directly in hundredths of an inch. It is not uniformly practicable to adjust the balance so as to indicate exactly zero when carrying the *empty* collector. Generally, therefore, a tare allowance for the empty gage must be deducted by the observer to ascertain the actual contents of the gage.

78. *Snow density attachment.*—Each gage is accompanied by a small copper bucket to be used in the manner described in paragraph 66 for obtaining the density of snow. The weight is determined upon the regular balance accompanying the shielded gage. Here again the proper *tare* allowance must generally be made, and the result is percentage density, water being unity, not inches of precipitation. Thus, a net dial reading of 14 for example means a snow density of .14.

79. Simultaneous measurements of the "catch" of the shielded gage and of the depth and density of freshly fallen snow on the ground enable an observer to determine with considerable certainty the errors of the shielded gage.

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80. It has been found that very wet, sticky snow may adhere to the inside top portion of such a collector as the 12-inch can. This action

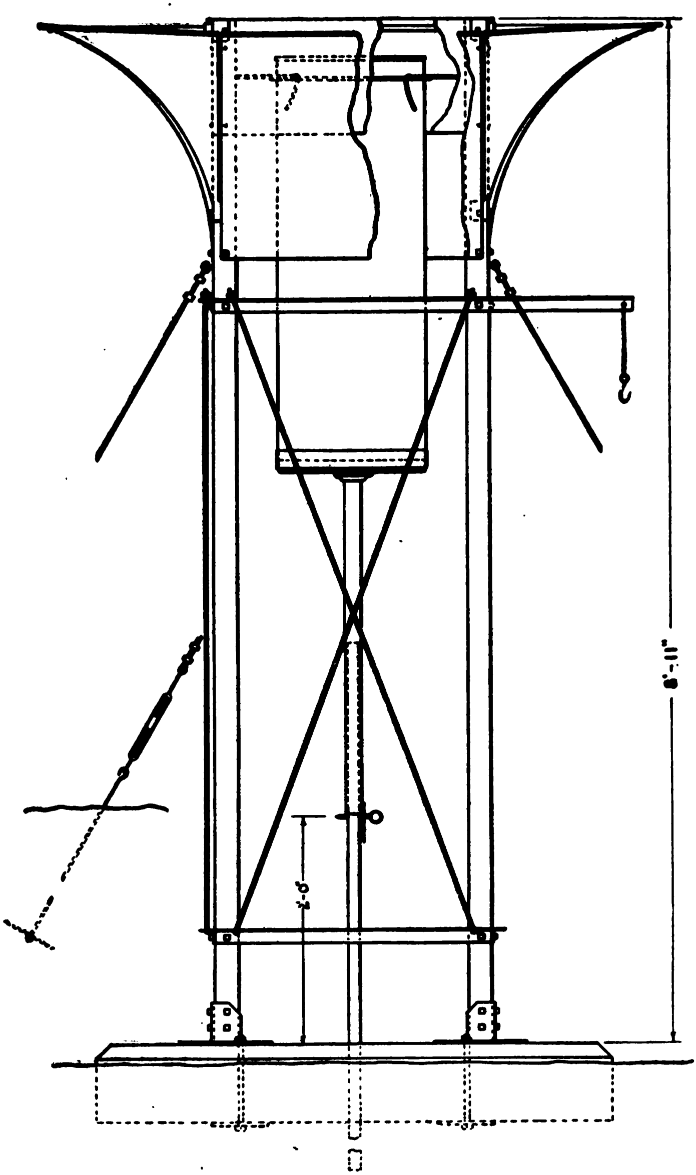

FIG. 6.—Shielded rain and snow-gage for frequent observations. Designed by C. F. Marvin.

may possibly cause the catch of the gage to be in error, but it is believed that the shields will so reduce the wind force at the mouth of the gage that the tendency of the snow to lodge at the top of the gage will

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be greatly reduced or eliminated. Even if the snow does stick to a greater or less extent at the top of the gage, it does not necessarily interfere seriously with the "catch," and when a measurement is made, the weight is determined with the snow in one position just as well as in another. This type of gage should not, therefore, be rejected on the ground of the sticking of the snow at the top until it has been fully demonstrated that the "catch" is seriously affected.

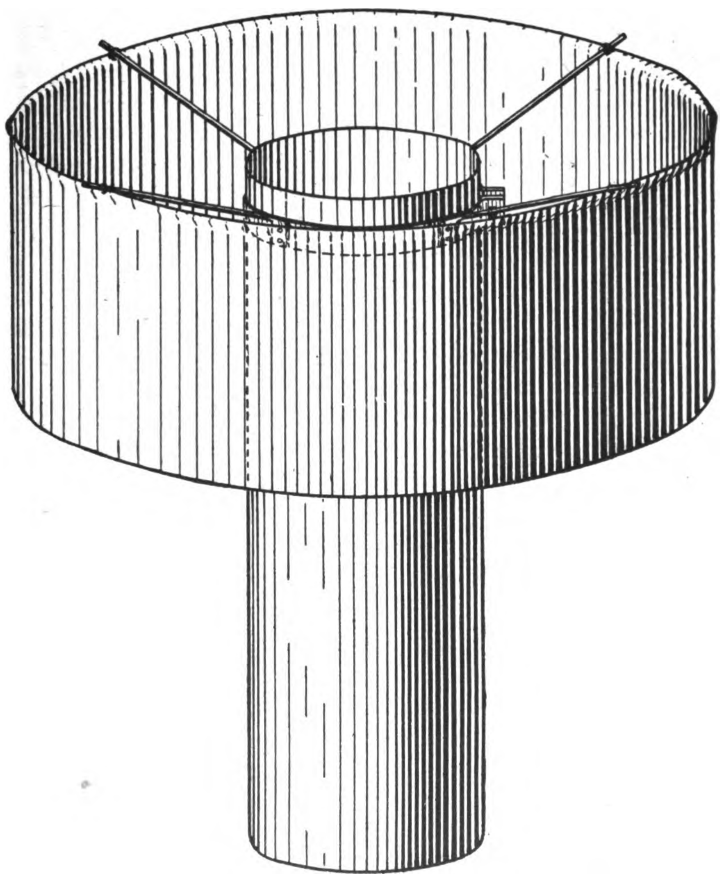

FIG. 7.—Cloth wind shield. Proposed by J. C. Alter.

The facility with which electrically-recording or dial-indicating gages of the tipping-bucket type can be attached to the shielded gage is sufficiently obvious.

81. Mr. J. C. Alter, at Salt Lake City, Utah, has proposed a novel construction of wind shield that seems to possess particular merits. The general idea is illustrated in fig. 7. A strong and flexible cloth apron, either of cylindrical or of conical formation, is disposed around and slightly above the mouth of the gage at a proper distance. It

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seems quite likely that tests will show this form of shield to be entirely satisfactory for snow-gages as well as rain-gages, and its simplicity and cheapness are very greatly in its favor.

OBSERVATIONS OF CLASS III.

82. *Combined snow tubes and density scales.*—The type of measuring apparatus now to be described is designed to secure accurate observations of the kind comprised in Class 3, viz, depth and water content of the whole layer of snow on the ground.

These data are of great practical value in all problems of hydrology, especially at the close of winter seasons and the general breaking up of ice-bound conditions. Observations of the whole snow layer upon the ground by cutting out and measuring tubular sections were first introduced in the Weather Bureau in the spring of 1905 by Prof. H. C. Frankenfield, incident to the work done by Horton and others. These observations are still being made at certain river stations in New York and New England.

83. Prof. J. E. Church, of Reno, Nev., has employed the method and made many difficult observations upon great beds of snow 20 to 30 feet in thickness in the Sierra Nevada Mountains. He introduced the use of spring balances for effecting the measurements, and otherwise improved the whole apparatus. The literature of meteorology suffers a distinct loss in that the excellent work of Professor Church along these lines has not as yet been published, and it is only partially known among his friends and acquaintances.

84. Fig. 8 shows the snow tube and density equipment devised by the writer for use by Weather Bureau observers. The tubes are made of galvanized sheet iron; they are about 2¾ inches in diameter, and are of greater or less length, according to climatic conditions of different sections. For the great majority of stations in the United States, tubes 50 inches long meet every ordinary requirement, but long tubes and sectional tubes are needed for proper measurement of deep beds of snow, such as are found in the western mountains. One end of the galvanized tube is reinforced by a piece of seamless steel tubing, 6 or 8 inches long and of smaller diameter, which is forced tightly *inside* the galvanized tube, the two being securely riveted together. The slightly projecting end of the steel tube is coarsely serrated with keenly cutting teeth to facilitate perforating icy incrustations, or ice itself in the snow beds.

85. The outside of the tube may be provided with a scale of inches which for permanence and accuracy is engraved on a separate piece of metal tape (brass, dull nickel finish) fastened to the tube. A ring secured to the side of the tube permits it to be attached to an appropriate spring balance for weighing. The dial of the balance is graduated and figured to show the water equivalent of the contents of the

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tube. The whole dial represents 10 inches of rainfall, with subdivisions to inches and tenths. As the individual spaces are about $\frac{1}{8}$ inch, estimations to hundredths can be made, if this order of accuracy is considered necessary.

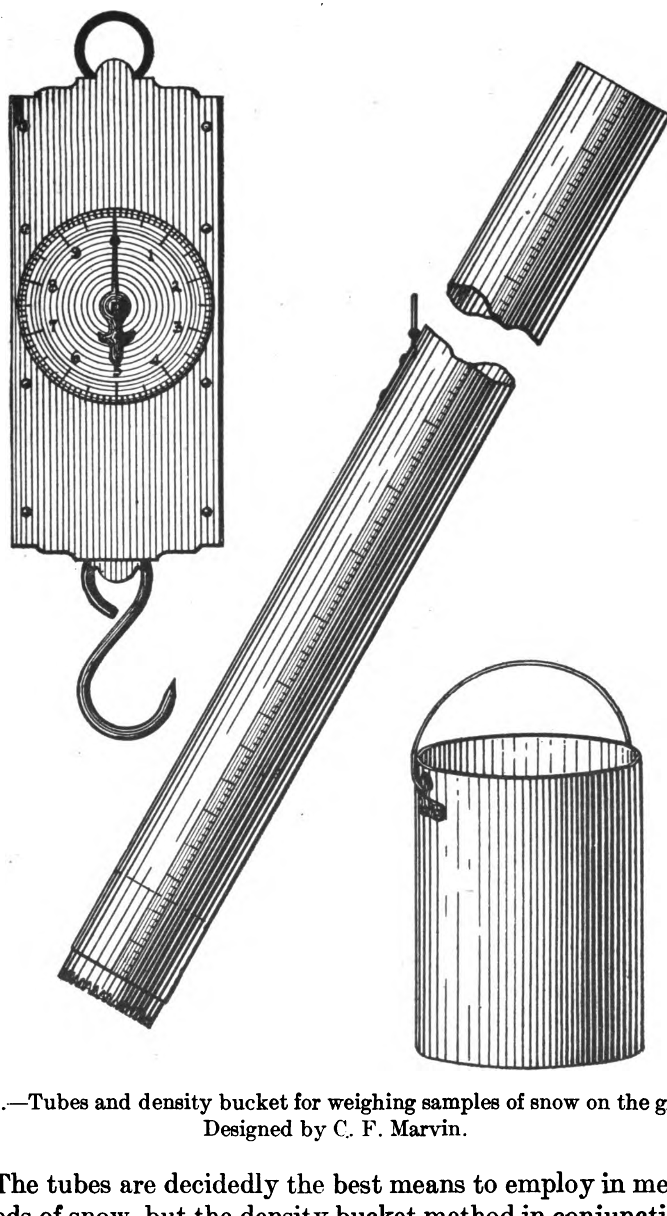

FIG. 8.—Tubes and density bucket for weighing samples of snow on the ground. Designed by C. F. Marvin.

86. The tubes are decidedly the best means to employ in measuring deep beds of snow, but the density bucket method in conjunction with a measurement of depth on the ground is probably more accurate in the case of thin layers, especially of light, freshly fallen snow.

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87. On this account each tube outfit is accompanied by an appropriate snow density bucket, to be used whenever circumstances require. In this case again the subdivisions of the balance dial are percentage units of density. The proper tare allowance for the empty tube or bucket must generally be determined and applied to readings.

88. It may be well to remark here that, in case o. measuring snow layers of small thickness with the tubes, better and more accurate average values can be obtained by cutting out two or possibly three sections at different points and collecting and weighing all of them in the tube at once. The observed net weight must of course be divided by the number of samples taken.

89. Great accuracy is attainable in reporting amount of snow on the ground, if observations are made by the tube and bucket methods described. Moreover, the observations are very easily made, and can be repeated in great numbers and diversity when required. The only limit to the accuracy and completeness of such data is the time and labor involved in procuring observations at numerous points.

OBSERVATIONS OF CLASS IV.

90. *Seasonal and semiseasonal gages.*—As we have already emphasized, our fundamental problem is first to devise methods and apparatus for *correctly* collecting precipitation, especially snow. The problem presented in the seasonal gage is simply one of conserving, either an automatic or other record of the precipitation, or the precipitation itself, until the observer can visit the relatively remote point of installation and take note of the record, or measure, and record the accumulated amount.

91. A very old device for securing a record of precipitation without preserving the precipitation itself, and one of great simplicity and excellence, is an adaptation of the tipping-bucket principle in which the tip of the bucket causes an index to move step by step over a dial. Certain gages of this kind for sale on the market are highly inaccurate, because the tipping bucket is made too small, but this is a matter that can be very easily avoided. There is scarcely any limit to the conditions and capacity to which gages of this kind may be applied, except that *rainfall only* can be measured.

92. To obtain automatic records of snow and rain over long periods of time involves greater expense than is warranted, in consideration of the little value that attaches to an automatic record. It is ordinarily quite enough to ascertain simply the amount of accumulated precipitation since the last observation.

93. Assuming that the precipitation can be properly collected, and retained for a considerable length of time, the writer has for some time favored the type of seasonal gage shown in fig. 9. This is nothing

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more than the gage shown in fig. 6 with the bottom of the collector greatly enlarged to give ample storage capacity to bridge over longer or shorter intervals of time between observations.

The gage is shown mounted upon a section of a steel tower simply to illustrate how these two pieces of standard equipment can be combined to meet conditions that require considerable elevation of the gage. Steel seems to be decidedly the lightest and most portable material available for structures of this character to be installed in relatively inaccessible places. It surpasses wood in permitting methods of construction adapted to the assembling of parts at destination by the use of simple tools and at the same time is stronger and more durable.

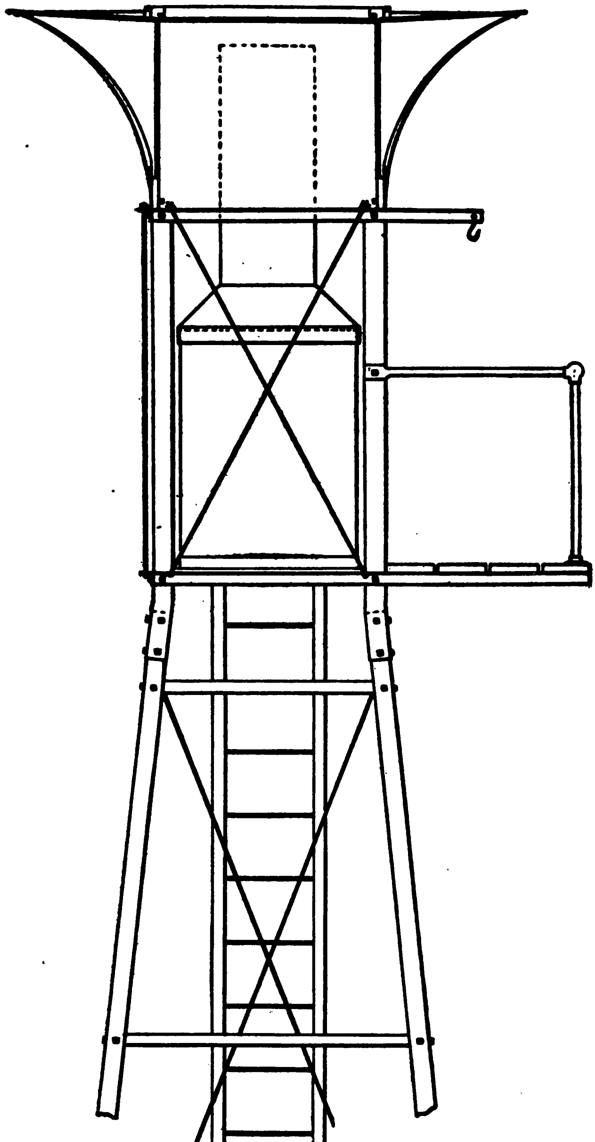

FIG. 9.—Shielded seasonal snow-gage. Designed by C. F. Marvin.

94. All measurements are made at time of observation by simply weighing the receptacle containing the accumulated precipitation. If snow incrustations or other conditions prevent the collector from being completely emptied at any time after an observation, the weight of the partly empty collector is simply recorded in the record and the can replaced on its support.

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95. The use of corrugations to overcome difficulties from freezing has been advocated by several observers. This and some other means seem promising, but it remains for the future development of the work to determine just what is necessary, and just what can be done.

96. A good deal of attention has been directed to the possible losses by evaporation, and its prevention, in seasonal gages of this kind, but in most cases the importance of this is far less than that of *correctly* catching the precipitation, a matter very largely ignored. Mr. Alter, at Salt Lake City, Utah, was probably the first one to propose and try the use of oil films to prevent evaporation of the contents of seasonal gages, and it seems difficult to find a more simple or effectual means than this, where it can be applied. See Monthly Weather Review, November, 1907, page 511.

97. *Depth of snow on ground.*—It is customary to provide for weekly, or less frequent reports, of the *depth of snow on the ground* from numerous points. The snow tubes and density buckets afford the best means for making observations of this class, but measurements of depth alone at numerous points may often prove of great value, and for this purpose vertical stakes of slender dimensions, and with graduations to *inches*, should be set up. Attention is invited to the inconvenience and incongruity of using either feet and inches or feet and tenths in recording snowfall. The *inch* is the unit always employed in expressing rainfall in English measure. If we measure the density of the snow and multiply by the depth *in inches* we get the rainfall-inch equivalent, whereas, if the foot be employed for the depth measurement, we get an inconvenient decimal of a foot that must then be converted to the inch unit.

98. Vertical snow scales should not be attached to trees unless the latter are of very small diameter. Not only is the ground at the base of the tree uneven and irregular, causing a decided error in the zero or starting point of the scale, but almost every one is familiar with the manner in which the snow drifts *away* from an obstacle like the trunk of a tree, so that observations from snow scales so installed, unless the tree is of very small diameter, can hardly be very accurate. Permanent vertical scales for depth of snow measurements must be of very slender proportions, and should be installed on a flat, even surface of ground of adequate extent.

99. A standard type of permanent construction that seems to permit of wide application to all sorts of conditions of exposure and snow depths is shown in fig. 10.

The scale is formed of one or of as many sections of steel angles as circumstances may require, one end being set in the ground and the other, if need be, braced in a vertical position by wire ties. The lightness of scales of this construction makes them much more portable, and consequently more easy to install at points difficult of access, than any other style of scale possessing equal durability and merit.

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Objection may be made to the smallness of the scale of graduation, but large scales seem incompatible with the quality of slenderness which these devices must possess.

SPECIAL INSTRUCTIONS.

100. In order to ascertain whether correct catches of snowfall on windy occasions can be secured by the use of wind shields on a type of gage such as is shown in fig. 6, a small number of these are being supplied to selected stations affording favorable conditions of exposure. The equipment will be installed, and the comparative observations made at these stations, in accordance with the following instructions:

101. *Exposure.*—The most favorable location for comparative observations is one in which the shielded gage can be installed in a large open field, entirely unsheltered, and subject to more or less windy conditions. At the same time a sheltered location in a glade or grove should be available in the near neighborhood, where good measurements of the snow on the ground can be made according to the principles and methods explained in paragraph 59. The standard 8-inch rain-gage must be installed in the sheltered locations for use in comparative measurements of rainfall.

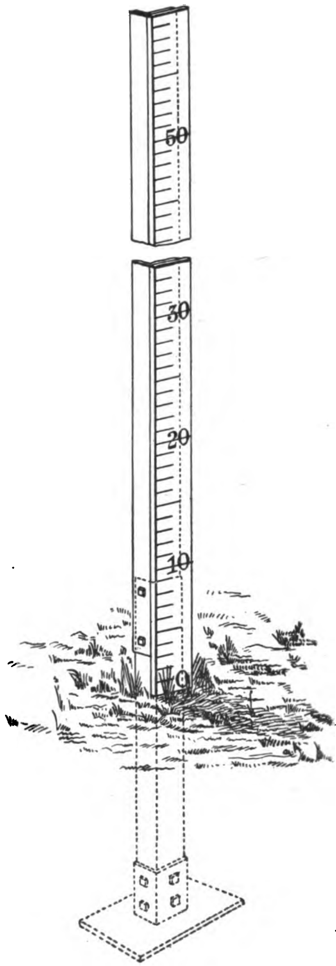

FIG. 10.—Vertical snow scale. Designed by C. F. Marvin.

102. *Installation.*—A small plinth of concrete, 6 to 8 inches thick, probably constitutes the best footing for the gage, but for temporary purposes a very good foundation can be made from two heavy pieces of timber, such as two railroad ties, or even two pieces of joist. These should be tied together by two cross pieces of lighter material secured *to the under side* of the main timbers, and all bedded in the ground level with the surface.

It is believed the erection of the gage will be easily understood from the drawing, without further explanation, especially to one having the parts before him.

103. *Observations.*—The chief object of these comparative measurements is to determine accurately the differences in the different

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methods of collecting and measuring snow. Great reliance is necessarily placed upon the care and intelligent judgment of the observer in getting at the actual facts.

104. In making measurements of the freshly fallen snow on the ground the errors due to the drifting must of course be avoided as far as possible. Whenever rain occurs, either with the snow or at any time between observations, this will be collected in the gage, but ordinarily it will not be correctly obtained from the measurements made on the ground. The observer must, therefore, always be careful to note under "remarks" when the comparative measurements have been affected either by rainfall or by more or less melting that may occur before observation, and that may also affect the ground measurement, but not the catch in the shielded gage.

105. Measurements of very light snows are necessarily more or less inaccurate; slight falls that are likely to continue for a day or two should be allowed to accumulate, and be measured at the end of the storm, rather than to try to get the small amounts for each day; otherwise observations will be made regularly after each *storm*, and measurements and records made as follows:

Enter all records on Form 1012 A—Met'l.

1. *Mean depth of snowfall found in snow bin*, where one is in use, computed from readings of the depth at the center and near each corner, according to the best judgment of the observer.

2. *Measurements of the catch in the sheltered snow-gage.*—The collector will be removed from its support and hung upon the balance provided for weighing it. *The number to be entered upon the record will be the dial reading opposite the index hand.* The whole revolutions of the index hand will be disregarded.

(*a*) After recording the dial reading, the collector will be completely emptied, removing it to a warm room if necessary. If it is impossible to empty the collector completely after measurement, it will again be weighed. The dial reading in this case will be entered on the record in the column headed "empty." *The true tare allowance or dial reading for the empty can* will be repeated in this column whenever the collector was actually completely emptied after measurement.

3 and 4. *Ground measurements.*—Measurements of the depth and density of the freshly fallen snow will be made regularly, so as to be comparable, as nearly as possible, with the bin and gage measurements; the methods described in paragraphs 58–71 being used for this purpose. The average of three or four measurements made at different places when possible should be taken, but the details of securing accurate observations will be left to the observer.

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(*b*) *Snow-tube measurement.*—The apparatus described in paragraph 84 will be used on each Monday to determine the depth and water contents of the whole layer of snow then on the ground. Here again the details of securing good observations with small layers of snow, either by the method of two or more sections, as described in paragraph 88, or the use of the density bucket, will be left to the observer.

6 and 7. *The force of the wind.*—In the absence of instruments for recording the velocity of the wind, observers are expected to estimate the force of the wind *only during the precipitation.*

(*c*) Only three degrees of force will need to be recognized, namely, calms and light winds, recorded *light,* winds of moderate force, recorded *moderate,* and finally brisk and high winds, recorded *high.*

It is desired that special care be exercised in discriminating between *light* and *moderate* winds. When the wind is strong enough to move and sway the boughs and limbs of trees visibly and more or less continuously the force will be recorded either moderate or high, according to the intensity of the effects. If the motion is only very gentle and infrequent, or absent altogether, the force will be reported light.

8. *Rainfall.*—When the precipitation is altogether in the form of rain, the comparisons will be continued between the shielded gage and the standard 8-inch rain-gage installed on the ground, or in a sheltered location as far as possible.

106. Regular stations of the Bureau to which the snow-density apparatus shown in fig. 5 has been sent, will make comparative determinations of the depth and density of the snow after snowfalls, and enter these upon Form 1012 A, together with measurements of the snow by any other methods that station officials are accustomed to employ in regular observational work. The headings of the form will be changed to meet the particular needs of the case, and a line, dated in full, will be used for each observation. One sheet will thus suffice for 31 observations and probably cover the whole season of snowfall. In submitting reports at the close of the season observers are requested to express the results of their experience in the use of the new apparatus as compared with other methods.

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