U. S. Department of Agriculture,
WEATHER BUREAU.

ANEMOMETRY.

A circular of general information respecting the theory and operation of typical instruments for indicating, measuring, and automatically recording wind movement and direction, with detailed instructions for the erection and care of those instruments of the Weather Bureau pattern.

CIRCULAR D, INSTRUMENT ROOM.

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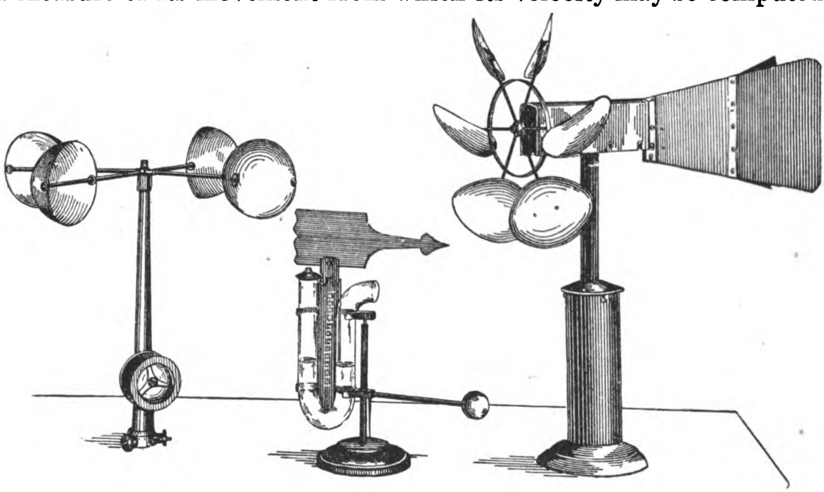
ANEMOMETRY.

MEASUREMENT AND REGISTRATION OF WIND VELOCITY AND DIRECTION.

I.—ANEMOMETER.

1. *Anemometer.*—This name is applied to various instruments of several distinct types by the use of which the *velocity or force* of the wind may be measured. Thus, there are (1) pressure and suction anemometers, which, in a more or less direct manner, indicate either by the amount of deflection of a spring or of a suspended plate of known weight, or by the rise of water in a tube, the pressure or force of the wind blowing against an exposed surface, or into or across a tubular orifice, and (2) rotation anemometers, which, by the continued revolution of exposed vanes or cups acted upon by the wind, give directly a measure of its movement from which its velocity may be computed.



a Robinson's cup anemometer. *b* Lind's pressure anemometer. *c* Richard's wind mill anemometer.

FIG. 1.

In almost every case each of these devices of either class requires some special arrangement which will automatically align the instrument in the direction of the wind to be measured. A noticeable exception to this is to be found in the so-called cup-anemometer invented, or rather developed and brought into use, by Dr. Robinson about 1846. This type has always been used by the United States Weather Bureau and is adopted by other meteorological bureaus, though great diversity exists in the dimensions and proportions of the different parts. It possesses many special advantages, and the pattern used by the Weather Bureau is peculiarly adapted to general meteorological work.

2. *Laws of action.*—Only in recent times has proper effort been made to ascertain accurately the true wind movement from these anemometers, or the effects of changing the dimensions and proportions of the parts.

Originally, Dr. Robinson studied his new instrument with considerable care, and, after some experiments, was led to conclude, that without regard to the dimensions of the cups and arms and for winds of high velocities, as well as those of low, the centers of the cups of his anemometer moved always just about one-third as fast as the wind. This relation has been persistently asserted, and almost without exception manufacturers have arranged the dial mechanisms and their graduations in accordance with this law, which is now well known to be erroneous. At low velocities the cups move slower than one-third as fast as the wind, while for higher and very high velocities they move relatively much faster than the one-third ratio. Not only this, but these factors and relations are considerably changed by increasing or diminishing the diameter of the cups or by lengthening or shortening the arms, so that each pattern of anemometer should have its particular law of relation determined by special experiment.

3. *Description of anemometer.*—The construction of the standard Weather Bureau anemometer is shown in Fig. 2.

4. *Cups and arms.*—The hollow cups shown in Fig. 1, *a*, are made of thin aluminium or brass, and are as nearly hemispherical as possible. These are securely fastened to small square steel arms set with their diagonals horizontal and vertical, respectively, so as to present the greatest strength to resist the bending action of the wind against the cups.

The cups are 4 inches in diameter, and the arms 6.72 inches long from the axis to centers of cups.

5. *Spindle and dial mechanisms.*—The spindle *c*, which forms the axis of revolution of the cups, is made of steel, or of brass and steel together, and has a worm or endless screw near the lower end. This engages a wheel (*m*) of fifty teeth, upon the axis of which is another worm or endless screw similar to the first. This second worm imparts motion to the small pinion (*l*), which in turn gives motion to a pair of dial wheels having 100 and 99 teeth, respectively, and graduations to correspond. The dial wheels are shown only in the anemometer on the right. In accordance with a simple mechanical principle, the dial wheel having 99 teeth must go just one tooth more than a complete revolution for each complete turn of the upper dial, which has 100 teeth, for in any given movement both dials, being driven by the same pinion, must each move exactly the same number of teeth.

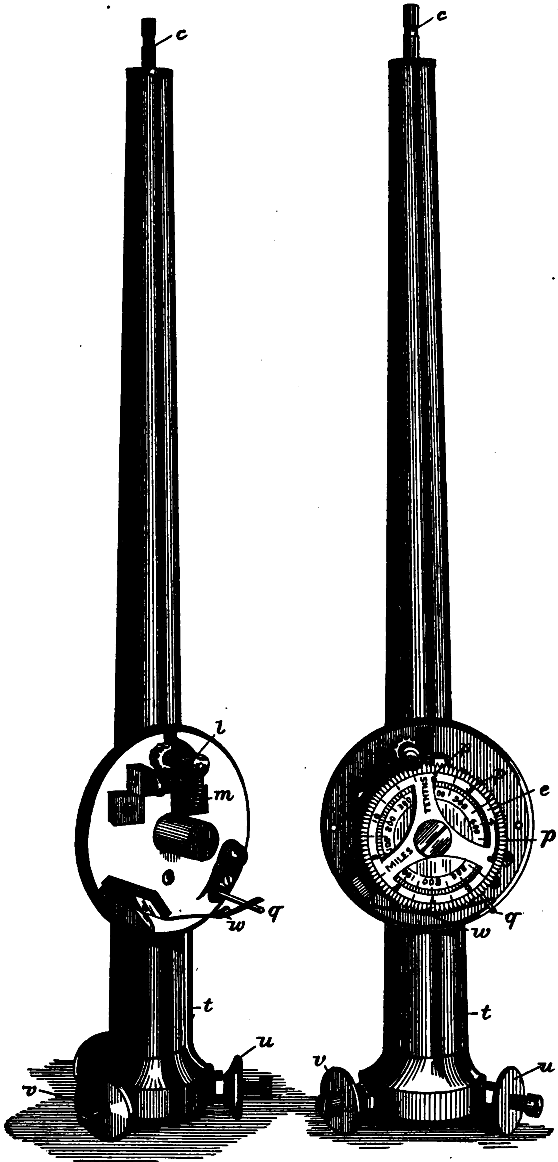


FIG. 2.—Standard anemometer, U. S. Weather Bureau.

This causes the lower wheel, for each revolution of the upper wheel, to move just one division of its graduations in reference to the latter, which motion may be observed by the aid of a zero or index mark arranged on the upper wheel to match the graduations below.

6. *Electrical registration.*—The dial wheel, e, is graduated into 100 spaces, and small "contact pins," p, are set into the wheel at intervals of ten divisions. At p' two of the pins are joined together, forming what is generally called the *tenth-mile* pin, or bridge-pin. Again, at w is shown a small spring, generally called the contact spring, one end of which is free and tipped on one side with platinum. Near this stands a pin, q, or contact post, also tipped with platinum. This part is insulated electrically, so that it does not rest in contact with any metal part of the anemometer. A small wire, protected by the metal tube, t, connects q with the insulated binding post, u. The most improved construction of the binding posts, u, and the electrical connection with the insulated post, q, is shown in Fig. 3. No part of the insulated wire is exposed, the connections being made within a closed cavity underneath the binding post, which is itself securely fixed to the base by two insulated screws.

A second binding post, v, is secured to the metal case, thus connecting, electrically, with the contact spring. The middle portion of the contact spring is formed so as to project into the pathway of the dial pins, and these, when the dial moves, glide in turn over the projection on the spring, causing it to deflect and bring the two platinum surfaces, already mentioned, into close contact for a short space of time. By these means the anemometer is made to close an electric circuit, and by the aid of other accessories, more fully described on pages 24–26, an electrical registration can be made of the movement of the dials. The tenth-mile pin causes the electrical circuit to remain closed the entire time of its passage, giving rise to a record for this particular double pin of a different character than that for the other pins; thus independently recording each revolution of the dial.

7. *Nominal value of dial graduations.*—A little thought in connection with what has already been said about the train of gearing, and the number of teeth in the various wheels, will show that just 50 revolutions of the cups will be required to move the upper dial one tooth, that is, one division, and 500 turns will move it ten divisions. Since the arms of the anemometer are 6.72 inches long the cup centers will move just $\frac{1}{3}$ of a mile in 500 turns, which, by Robinson's principle, represents an actual wind movement of just one mile, and the graduations of the dial are, therefore, designated miles and tenths of miles.

8. *Dial readings, how made.*—The reading of the anemometer dials, shown in Fig. 4, is 666.3 miles. To read the dials seek out first

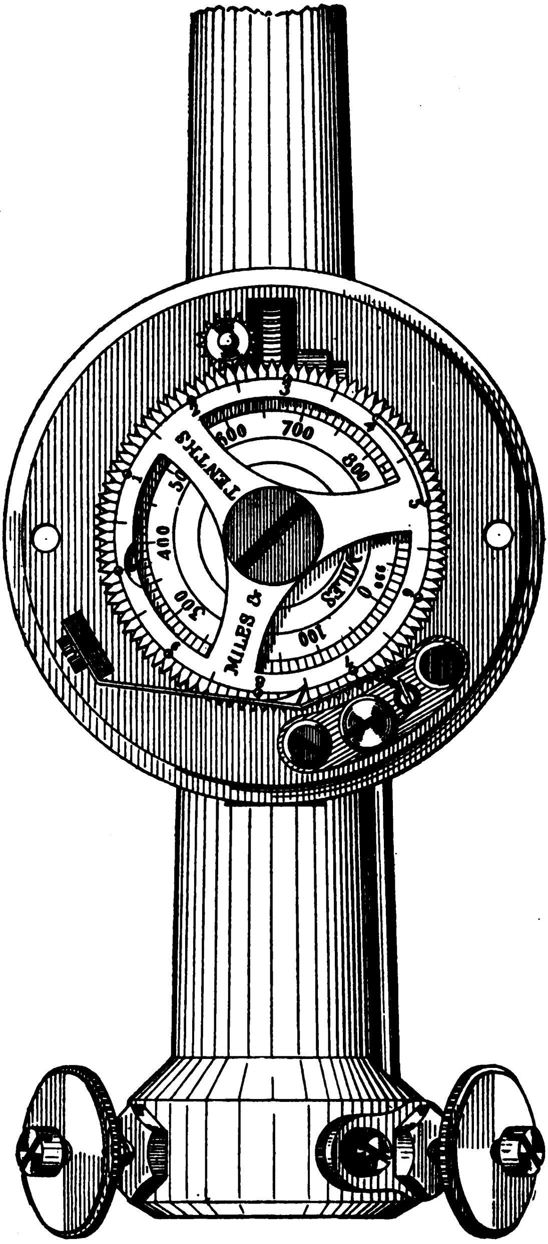


FIG. 8.—Improved anemometer.

the index mark upon the inner edge of the outer dial and observe the value of the graduation on the lower dial *next below the index*

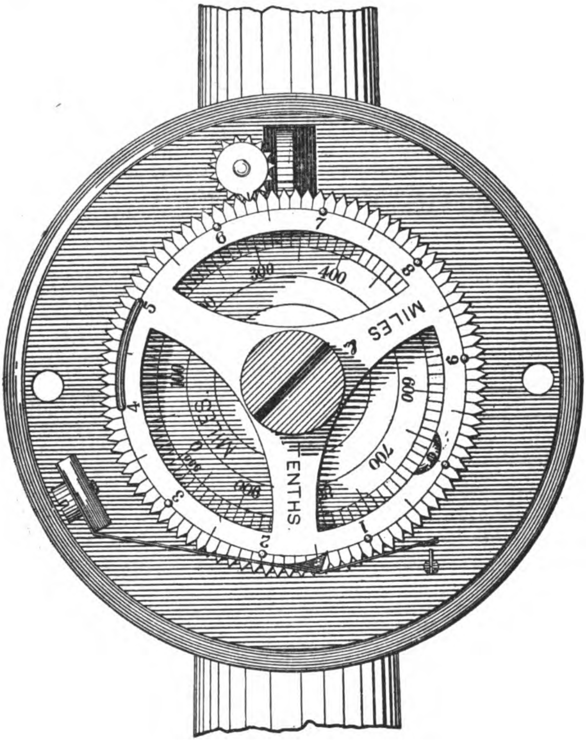


FIG. 4.—Anemometer dials.

mark. In the present case this is 660. Next, read the graduation upon the outer dial opposite the index a little to the left at the top, or, in the absence of a special index, the graduation opposite the center of the small pinion which gives motion to the dials. In the figure this is 6.3, hence the dial reading is $660 + 6.3 = 666.3$ miles. The dial reading in Fig. 3 is 372.5 miles.

Attention is called to the fact that but four graduation marks appear in the space on the lower dial between 950 and the next long line or the zero mark, that is, the highest possible count upon this system of dials is 990 miles, whereupon the dials return to their zero positions and the count begins over again. This is indicated by the small figures 990 near the zero mark.

9. *Caution against mistakes.*—A mistake of 10 miles is sometimes easily made in dial readings by not being careful always to read from the lower dial the division *next below the index line.* For example: in the figure the 670th line is almost opposite the index, still, strictly speaking, these cannot come exactly opposite until the index line itself is opposite the driving pinion. We must, therefore, take the line below, namely, 660. Sometimes in loosely fitted gearing the

index, in such a case as in the figure, may be even a little beyond the 670th line, still we must take the 660th line, since the reading of the outer dial, viz., 6.3, being so near 10, of itself indicates that the index line must be near to but not quite coincident with the 670th line.

Observers should study this matter with the aid of the anemometer dials, placing the index line in different positions, especially first a little to one side and then to the other of the pinion, and noting carefully the results. Also to study the effects of looseness in the gearing.

10. *True value of dial graduations.*—The exact value of the dial graduations of the standard anemometer has been made the subject of considerable experimental study by the Weather Bureau. For this purpose a very large whirling machine was set up in the large closed court of the Pension building. This apparatus consisted of a long horizontal arm, supported near one end upon a vertical axis about which it could be made to revolve at any desired velocity. The extreme end of the arm was 35 feet from the axis, and upon it could be placed the anemometer to be tested. The movement of both the whirling arm and the anemometer cups was fully recorded, electrically.

11. From the results of these experiments, and subsequent comparisons in the open air, the following equation has been adopted to express the relation between the motion of the cups and the wind velocity:

$$\text{Log. V} = 0.509 + 0.9012 \log. v;$$

where V is velocity of wind in miles per hour and v is the linear velocity, also in miles per hour, of the cup centers. This equation applies only to the Weather Bureau anemometer having 4-inch hemispherical cups on arms 6.72 inches long.

12. The table below gives the corrected velocities corresponding to observed velocities up to 90 miles per hour:

Wind velocities, as indicated by Robinson anemometer, corrected to true velocities.

(Miles per hour.)

Indicated velocity.	+ 0	+ 1	+ 2	+ 3	+ 4	+ 5	+ 6	+ 7	+ 8	+ 9
0	......	......	......	......	......	5.1	6.0	6.9	7.8	8.7
10	9.6	10.4	11.3	12.1	12.9	13.8	14.6	15.4	16.2	17.0
20	17.8	18.6	19.4	20.2	21.0	21.8	22.6	23.4	24.2	24.9
30	25.7	20.5	27.3	28.0	28.8	29.6	30.3	31.1	31.8	32.6
40	33.3	34.1	34.8	35.6	36.3	37.1	37.8	38.5	39.3	40.0
50	40.8	41.5	42.2	43.0	43.7	44.4	45.1	45.9	46.6	47.3
60	48.0	48.7	49.4	50.2	50.9	51.6	52.3	53.0	53.8	54.5
70	55.2	55.9	56.6	57.3	58.0	58.7	59.4	60.1	60.8	61.5
80	62.2	62.9	63.6	64.3	65.0	65.8	66.4	67.1	67.8	68.5
90	69.2	......	......	......	......	......	......	......	......	......

NOTE.—Corrections need not be applied below velocities of 11 miles per hour, where fractions of miles are not desired.

13. *Pressure of wind.*—It sometimes becomes desirable to know the pressure exerted by the wind upon a surface exposed at right angle to the wind's direction. For this purpose flat plates or cylinders or

spheres may be arranged with various spring and recording mechanisms, so that the wind pressure against such surfaces will be indicated and recorded by the amount of deflection produced in the spring. Such records, owing to their extremely changeable character and the difficulty of securing accuracy, have never proved very satisfactory and such instruments are very little used.

14. *Relation of wind velocity and pressure.*—The relation between mean pressure of the wind against exposed surfaces and the corresponding wind velocity has never been worked out with entire satisfaction. Nevertheless rather better results can be obtained by using such facts as are known than to attempt to measure the wind pressure directly. Experiments were made by this Bureau to determine the relation between wind velocities and pressures for certain limited conditions by exposing squarely against the wind variously sized plates of from four to nine square feet of surface. The deflection produced in springs of known strength by the pressure was continuously recorded by a pencil marking upon a revolving cylinder of paper. At the same time and on the same sheet of paper was also electrically recorded the velocity of the wind as indicated by an anemometer exposed near the pressure plate.

From these experiments, taking into account the corrected velocities as given by the above table, it is found that wind pressures are not so great as generally computed heretofore, and are quite accurately given by the following equation:

$$P = .0040 \frac{B}{30} SV^2.$$

P = pressure, in pounds avoirdupois.

S = surface, in square feet.

V = corrected velocity of wind, in miles per hour.

B = height of barometer, in inches.

For stations near the sea level where the barometric pressure does not differ much from 30 inches the ratio $\frac{B}{30}$ need not be considered. For elevated stations, however, with barometric pressures ranging from 24 to 30 inches, the effect of this must be considered.

Table of wind pressures (pounds per square foot).

Indicated velocity.	+ 0	+ 1	+ 2	+ 3	+ 4	+ 5	+ 6	+ 7	+ 8	+ 9
0	......	......	......	......	......	.104	.144	.190	.243	.303
10	.369	.433	.511	.586	.666	.762	.853	.949	1.05	1.16
20	1.27	1.38	1.50	1.63	1.76	1.90	2.04	2.19	2.34	2.48
30	2.64	2.81	2.98	3.14	3.32	3.50	3.67	3.87	4.04	4.24
40	4.44	4.64	4.84	5.07	5.27	5.51	5.72	5.93	6.18	6.40
50	6.66	6.89	7.12	7.40	7.64	7.88	8.14	8.43	8.69	8.95
60	9.22	9.49	9.76	10.1	10.4	10.6	10.9	11.2	11.6	11.9
70	12.2	12.5	12.8	13.1	13.5	13.8	14.1	14.4	14.8	15.1
80	15.5	15.8	16.2	16.5	16.9	17.3	17.6	18.0	18.4	18.8
90	19.2	......	......	......	......	......	......	......	......	......

15. While the formulæ herewith presented give results, it is believed, more nearly correct than before obtained, yet, owing to the

great difficulty of making accurate experiments at high velocities, these adopted values can be regarded as only approximate.

16. Great dependence cannot be placed in these values for indicated velocities beyond 50 or 60 miles per hour, as thus far direct experiments have not been made at the higher velocities, though it is probable the corrected values are throughout much more accurate than values computed from older formulæ and uncorrected wind velocities.

17. *Essential characteristics of good anemometers.*—The weight of the cups and moving parts should be reduced to a minimum to avoid great momentum and to reduce the pressure upon the lower end of the spindle. The pivot bearing at this point should be very small in diameter, slightly rounded and convex, and of very hard and highly polished steel. This should rest upon a small, flat, steel plate, also hardened and polished and immersed in oil.

18. An excellent construction of this portion of the anemometer is shown in Fig. 5. A comparatively large opening is closed by the cap, *A*, which is held by spring friction, but is secured from being lost by the slotted link, *L*, attaching it to the anemometer. This opening gives convenient access to the worm and lower end of spindle for inspection and oiling. The pivot bearing for the end of the spindle, *C*, will be readily understood from the drawing. *S* is a small flat disc of hardened and polished steel, resting loosely in the bottom of the cavity of the screw, *B*, the annular space above being filled with oil.

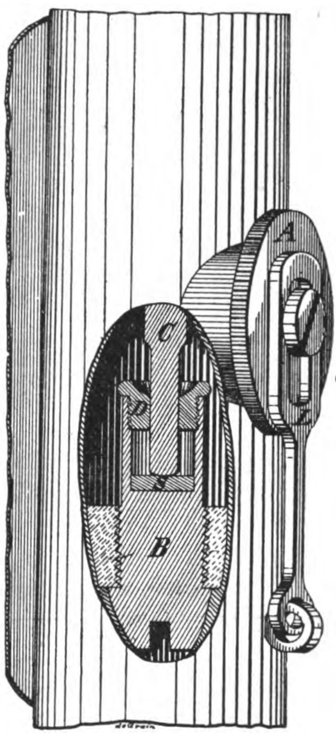


Fig. 5.—Anemometer bearings.

19. The train of gears should be very freely moving, especially the worm wheel, *m*, Fig. 2, because frictional resistance in its movement is more prejudicial than in the other dial mechanisms, owing to their very slow motion.

20. The most prejudicial resistance in any part of the anemometer when in good condition is that occurring in the top bearing of the spindle. This bearing should first be made very smooth and polished and afterwards kept clean and freely lubricated, if good results are to be expected. *When well made and properly cared for the anemometer will show only a very little wear after years of exposure, even with comparatively high winds.*

21. The small bright spot upon the lower end of the steel spindle,

where it wears against the steel plate, should never be larger than a pin head. If this portion becomes dry of oil by neglect, as sometimes happens, it will quickly wear flat and introduce a very great amount of friction. The instrument can than be restored to good condition only by recutting and polishing the pivot end, also the small plate, so as to perfectly remove all previous scratches.

22. *Simple tests as to the friction of anemometers.*—Whether or not the bearings of an anemometer are sufficiently frictionless can be told by the following simple tests: Remove the cups and holding the anemometer vertical, twirl the spindle smartly as you would spin a top, between the thumb and finger. If properly fitted and twirled the spindle should make many revolutions and not stop quickly, but spin freely after starting. This test succeeds best when there is only a little oil on the top bearing of the spindle.

23. A better test is to press the forefinger of the right hand *strongly* sidewise against the spindle above the bearing, see Fig. 6, and slowly draw the finger across the spindle. The latter should always revolve in its bearing and not slide on the finger, as will frequently happen.

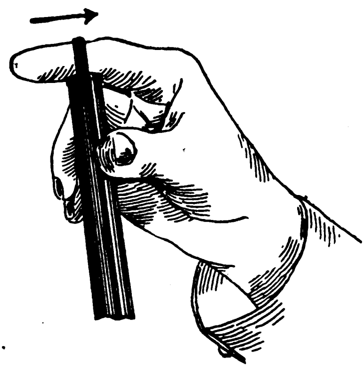


Fig. 6.—Friction test.

24. These tests, however, will not always show the dial mechanisms to be in good order. To determine this latter the spindle must be removed. Then, with the finger-tip or nail of the middle finger of the right hand, impart a quick impulse to the worm wheel, *m*, Fig. 2, thus setting the whole train of wheels in motion. Some practice is required to give a good impulse. The force must be applied *exactly* in the plane of the wheel else the latter will be thrust sidewise in its bearings and revolve only sluggishly If the gearing is properly made the worm wheel will run 40 or 50 revolutions before stopping, and 4 or 5 dial pins will glide over the contact spring.

25. Instruments are not in good condition that will not behave properly under these delicate tests. In many cases, however, it is only a little dust or finely ground metal, etc., in the bearings that causes the friction, and the instrument needs cleaning and new oil.

26. *Suggestions about oiling anemometers.*—The only oil suitable for use on these instruments is the Ezra Kelly clock oil. The train of gearing and dials need be oiled only at long intervals, and then but a very little oil should be applied to each point. A very small quantity should be placed upon the inclined face of the projection on the contact spring.

27. The bearings of the spindle and the worm require more frequent

and copious lubrication. A greater supply than will remain in the bearing, however, is simply wasteful. One drop of oil, such as will generally adhere to a match or similar pointed stick, applied once a week, is, in most cases, sufficient for the parts of the spindle. The worm needs less than this. The cups must be removed to properly oil the upper bearing. The oil must be applied directly to the points at which it is needed. Anemometers, as now constructed, admit of doing this with very little trouble.

28. *Durability of anemometers.*—One of the official anemometers in use at this office has been exposed continuously, except for a few moments from time to time for cleaning and oiling, *for over* 15 *years*, and yet has never had a single part renewed, and shows scarcely any perceptible wear. The instrument is, in fact, exactly as good as new. In view of this fact, as well as the prolonged use of other instruments at this and other localities, observers should bear in mind that very great durability is reasonably expected of anemometers, and that any failure in this respect is a strong indication of neglect, either because of careless attention or lack of knowledge as to the proper manner of caring for the instrument.

29. *Neglected anemometers.*—If, in any event, by neglect or otherwise, the bearings of an anemometer become dry of oil, they will, in a few hours or less, in high winds, grind and wear themselves badly, becoming rough and seriously injuring the instrument. On such occasions the anemometer will nearly always emit a shrill squeaking or other very audible sound that is a sure indication of its imperfect condition, and trained and careful observers will always be on the alert for sounds of this kind. If this state of affairs continues, and especially in fresh winds, the abrasion of the spindle in the top bearing will presently cause it to lock tight, exactly as a carriage wheel becomes locked under the conditions so commonly known as a "hot-box." Nothing but gross neglect and insufficient lubrication ever produce this condition, and the wind movement by such an anemometer, especially if light, will afterwards be largely deficient unless the injured parts are renewed.

30. An anemometer heard squeaking should be immediately removed from the support and exchanged, or thoroughly cleaned and freshly oiled before attempting to use it further.

31. *Suggestions about cleaning anemometers.*—While an instrument, if properly cared for, will run for many years and still remain in perfectly good condition, yet instruments should be critically examined as often as once each month, and if the bearings of the spindle and the oil about them appear to be in a very dusty and dirty condition, or the oil is thick or dry, the instrument should be replaced or removed and cleaned, having regard to the following points:

32. Generally the spindle and its bearings, both upper and lower,

will be the parts that specially need cleaning. Only *clean* cotton or other soft cloths should be used, and the parts should be rubbed quite dry and clean, and all old oil removed thoroughly before any new oil is applied; a little kerosene or benzine is helpful in this connection. It often happens that under tests an anemometer newly cleaned will exhibit greater friction than before. This arises from the fact that in handling the parts, and perhaps in wiping the bearings with more or less dusty and dirty rags, small dust and other gritty particles make their way into the bearings and increase the friction. These points should, therefore, be had in mind always and guarded against in all manipulations.

33. If the anemometer has not injured itself by running without oil, the top bearing of the spindle will be smooth and bright and the lower pivot still round and with only a small bright spot in its center, a corresponding bright spot being noticeable on the plate beneath. On the other hand if insufficiently and improperly oiled or neglected, the bearing will contain injurious scratches more or less serious, according to circumstances, and the lower pivot end will have a large flat spot and bad scratches, with corresponding injuries in the plate beneath. *Such an anemometer cannot give accurate results.*

The top bearing is best cleaned by drawing a piece of clean cloth back and forth through it a few times, taking care to avoid leaving dust or lint behind when the cloth is withdrawn.

In general it is not necessary to remove the lower pivot bearing, but if the spindle is worn and flattened on the end, or if from careless attention or the use of poor oil and long exposure this bearing is gummed, it must be removed and thoroughly cleaned. The small screw-cap, *D*, Fig. 5, should be taken out, and after cleaning out the oil in the cup-like space, the small steel plate at the bottom should be shaken out. This is loose in the cup, though sometimes the adhesion of the oil makes its removal difficult. If in good condition, the plate, *S*, should be highly polished and *flat*, not with a noticeable hollow worn in the center. In replacing this bearing it should be about half filled with good oil and screwed up tight into the anemometer socket.

In replacing the spindle a drop or two of clean oil is first applied to the inside of the top bearing, which may then be placed on the steel spindle after it also has been rubbed over with a few drops of oil. The pivot end and worm are then oiled and the spindle with the top bearing upon it is inserted within the tube of the anemometer and without rubbing the sides of the tube, if possible. The top bearing need be tightened only moderately.

There is generally less necessity for cleaning the dial mechanisms, but, if these are taken apart, great care should be used to avoid injury to the sharp points and teeth of wheels and the contact spring. This latter ought not be taken out at all, and should not be bent or displaced from its original form.

34. *Adjusting contact spring.*—In giving proper form to a contact spring that may by accident be in need of adjustment, it should be bent so that the advancing contact pins first strike the little projection on the spring about midway between its base and point. The outer portion of the spring may then be bent so that its platinum point is brought firmly into contact with the post, *q*, Fig. 2, *only during the last portion* of the movement of the pin across the spring. *Do not bend the contact spring so that the pins rub along the spring itself before reaching the projection.* Adjust the spring with the idea of producing perfect electrical contact with the least possible frictional resistance, and for a short duration of contact.

Always carefully brighten the platinum contact surfaces. A roughly scratched surface is very bad for good contact; the surface should be bright but smooth.

35. *Exposure of anemometers and supports.*—On account of the great interference offered by buildings and other natural obstructions to the free movement of the wind, its velocity is much less in the vicinity of these obstructions than above; therefore, in selecting the location for an anemometer preference should be given to the highest obtainable point in the vicinity of the station, and some rigid support should be used to elevate the instrument as far as practicable above the immediate influence of the office building itself.

The most approved pattern of anemometer support is made up of wrought-iron pipe, in exactly the same way as the wind-vane support shown in Fig. 7, page 18. The top of the support is capped with a small iron pin fitted to carry the anemometer. Iron footsteps clamped to the pipe form a secure ladder, by which the anemometer may be reached and examined, oiled, dial readings made, etc.

Very often the anemometer is exposed upon a cross arm fixed upon the wind-vane support, as shown at *B* in Fig. 7.

It is not found practicable, in the experience of this office, to use supports of greater height than from 18 to 24 feet, as they cannot readily be made sufficiently rigid and secure.

The support must be set up so that the anemometer on top or on the cross-arm is as perfectly vertical as possible.

ANEMOSCOPE.

36. *Anemoscope.*—The vane, or anemoscope, for showing the direction of the wind should be highly sensitive to variations in wind directions but at the same time should possess a property of steadiness that will prevent the vane, when suddenly shifted in direction, from going altogether too far and thus giving erroneous indications as to the true character of changes in the wind direction. It is a very common mistake to imagine that large and heavy vanes are necessarily better and more steady than smaller ones. It is true they

may often seem to vibrate and oscillate in the wind less than lighter vanes, but the seeming steadiness is really a defect, and is due to excessive friction which prevents the vane from responding to any except very strong winds, and then its position of rest generally differs widely from the true wind direction.

If a vane has weight and moves in frictionless bearings it will always oscillate more or less in adjusting itself to a new and steady wind direction. Such a vane would continue to oscillate indefinitely except for the dissipation of energy by the eddies produced in the air flowing around the tail. When once at rest such a vane will be exactly in the direction of the supposed steady wind. The energy of oscillation will be dissipated more quickly if there is some friction in the bearings, but in this case the friction may hold the vane at rest in a position more or less out of the true wind direction.

The ideal vane would be frictionless and *without weight*. It would follow perfectly every change in wind direction and without exhibiting any oscillations except those of the wind itself. Here, again, friction in the bearings would prevent the weightless vane from taking the exact wind direction. In fact, under all circumstances, friction in the bearings of a vane is highly objectionable and must always be made as small as possible. A properly designed vane should, therefore, be as light as possible, relative to the extent of surface, and move in bearings with a minimum friction.

Such a vane will oscillate only a little more than the wind itself. Owing to the whirls and eddies of limited extent always found in air currents, a short vane, if well made, will show many sudden and great changes of wind direction that would produce little or no effect on a larger vane with a comparatively long tail. The latter is, therefore, much to be preferred.

37. *Spread-tail vanes.*—When a perfectly straight, thin, vane stands exactly in the direction of the wind, there is, strictly speaking, no lateral pressure upon it whatever, and even for slight deflections the pressures are very small. If, however, the tail be spread somewhat, a lateral pressure acts upon each side of the tail and tends, as it were, to hold the vane steadily in its position. Moreover, for slight deflections of the vane from the wind direction a spread tail presents a greater extent of surface to the wind than a straight-tail vane of the same dimensions.

The spreading of the tail also forms various angles and irregular partly closed spaces, which produce many eddies and whirls in the air whenever the tail moves; this, as was mentioned above, absorbs energy and is of sensible advantage in suppressing oscillations.

There is but one proper way to seek to suppress the oscillations of a vane; namely, by interposing some sort of frictionless obstruction to its *sudden* movements, such as the resistance of vanes or blades moving in oil. This prevents sudden shifts in the vane, but does not prevent the vane from slowly adjusting itself exactly in the direction of any steady current.

38. *Standard vane, Weather Bureau.*—The standard vane of the Weather Bureau and its support, with contact box and electrical contacts, are shown in Fig. 7. The construction, as far as practicable, embodies the essential principles of the ideal vane mentioned above. Owing to the considerable dimensions and extremes of exposure to which wind vanes are subjected it has long been a difficult question as to how best to avoid excessive friction in the mounting, and at the same time secure durability with little or no attention, and under the corroding effects of moisture, etc. A vane with ball bearings is often suggested, but unless these are nicely constructed, with hardened surfaces, such a bearing will quickly wear badly, especially if not oiled, and if oiled will accumulate dust and soot in a most injurious manner. For a long time the Service has been using a form of vane supported and revolving upon a system of three wheels moving between two circular plates. This bearing does not require lubrication at all, and in the main has been generally satisfactory. Some minor defects in the construction have caused trouble, but recently the design was materially altered with a view to securing such construction that when set up even by untrained mechanics or others with only imperfect ideas of such things, the device could not fail to work with great freedom. In other words, the design itself must admit a reasonable amount of poor and thoughtless workmanship in the erection of a vane without its free action being in the least impaired. Many radical changes were made to realize these conditions, and the newly designed vane and support, with electrical contacts, are shown in Fig. 7. The axis of the vane is formed out of a solid iron rod, *a*, about $\frac{5}{8}$ inch in diameter, and about 42 inches long. The tail of the vane is of thin wooden boards, spread apart about 9 inches at the end. These boards are bound together and reinforced by suitable iron bands, of which the two on the edge are prolonged to carry a small counter-weight, *w*, and the arrow-point, *o*. The rod *a* is tapered at the top portion and squared at *f*, as shown in the enlarged section at *A*, where it fits closely into a corresponding hole in the lower iron-bound edge of the vane, the rod and vane being held together by the spear-head nut, *g*. The entire weight of the vane with the moving parts connected thereto is supported upon the three anti-friction rollers, seen enlarged at *A*. These are of hard brass and are mounted in the carrier or frame, *h*, which fits loosely around the solid rod and yet centers and otherwise keeps the wheels in their proper positions. The bell-cover, *k*, is made of hard brass and turned out true and smooth on the inside. It fits the solid rod a little loosely and rests against the shoulder formed by the nut, *n*, which is securely

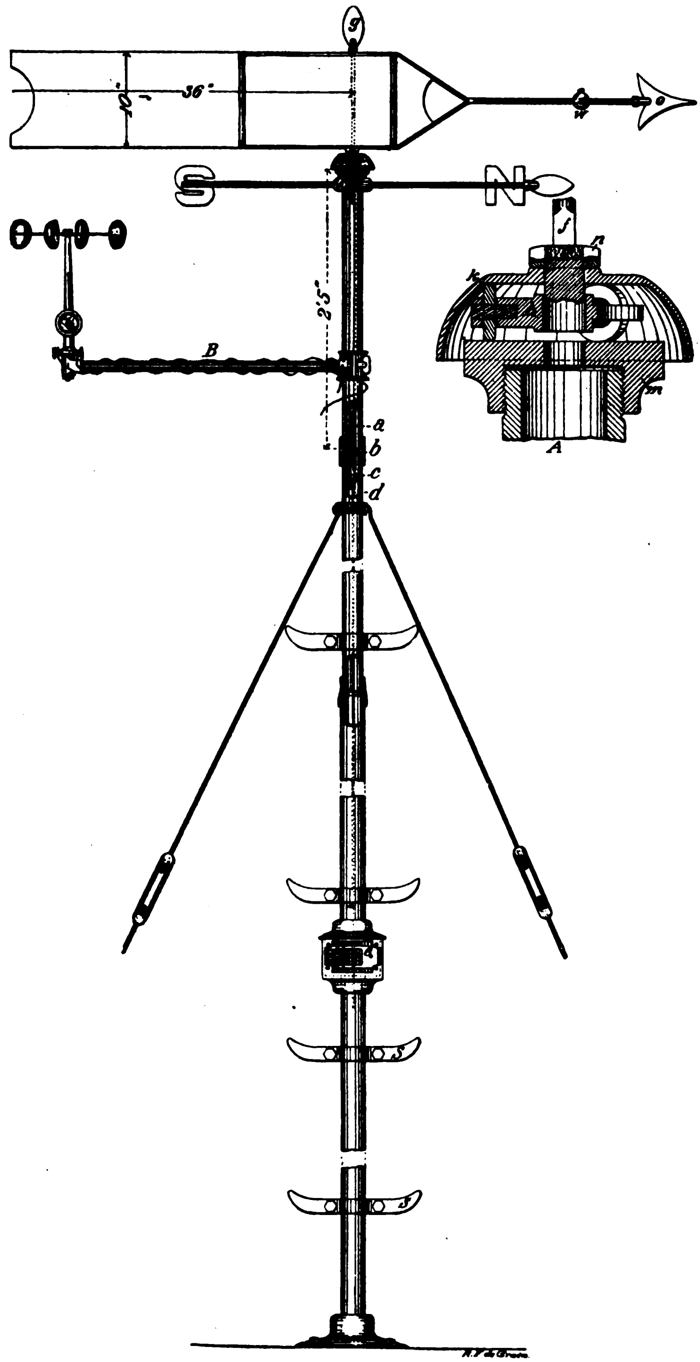


FIG. 7.—U. S. Weather Bureau combined wind vane and anemometer support.

screwed to the rod. The bell-cover, by being fitted loosely in this manner, is able to center itself and distribute the weight equally over the three anti-friction wheels. The cap is faced with hard brass turned true and smooth, and forms one of the pair of surfaces between which the anti-friction wheels roll, the other being the under surface of the bell-cover. The axis of the vane is guided laterally in passing through the cap at the top, and at the bottom in the brass bushing of the coupling, *b*. The lateral pressures, are, as a rule, very small, and no special provision is made for reducing friction in this respect, except to insure a loose fit and smooth holes. The cap, *m*, screws upon one end of a short piece of 1½-inch wrought-iron pipe, and the coupling with its bushing upon the other end.

39. The vane and short axis, as described above, including the short piece of 1½-inch pipe, is a complete mechanism within itself, the inside rod being short and straight, a condition necessary for perfectly free movement. This construction readily admits placing the vane upon any suitable support and at any convenient height. The standard support is made out of wrought-iron pipe, and becomes extremely secure and rigid when stayed with three guy rods, as partly seen in the figure. These latter are provided with turn-buckles for tightening, and are secured to the roof by iron shoes.

If electrical contacts or a ceiling dial are used the axis of the vane is extended by the addition of a sufficient length of ⅛-inch gas pipe, the outside diameter of which is about $\frac{5}{16}$ inch. One end of this pipe is screwed firmly into a reducing coupling, *c*, with which the lower end of the solid rod of the vane is fitted. The inside rod thus extended will probably not be quite straight, but can be easily bent nearly so, and if slightly out of true the matter is not serious, since the very slender pipe is comparatively flexible and adapts itself to its constraints with only slight frictional resistance.

40. *Foot-rests.*—To afford access to the top of the vane support, and especially when a cross-arm is attached for the support of an anemometer, iron foot-rests, shown at *S*, in Fig. 7, are clamped to the pipe at intervals of about 18 inches.

41. *Anemometer cross-arms.*—A horizontal arm is often attached to the wind-vane support at a point about 3 feet below the vane. The outer end of this arm carries a pin upon which anemometers may be exposed. The anemometer cups are then about 18 inches below the level of the under edge of the vane and at a distance of about 30 inches from the support itself. This cross-arm is shown in the figure at *B*.

42. *Contact box.*—The contact box, within which the devices for securing electrical registration are placed, is of cast-iron, and to be easy and convenient of access at any time, is usually inserted at about the height of one's head from the base. Rain, etc., are perfectly excluded by a close-fitting cover.

43. The contact mechanisms are shown separately in Figs. 8 and 9, and are partly seen in position within the contact box at *e*. This device consists essentially of two parts: 1st the "cam-collars," so-called, shown separately in Fig. 8, and the contact plate and springs seen in Fig. 9. The device in Fig. 8 consists of four exactly similar cams, the acting portion of which embraces exactly three-eighths of a circumference. These are arranged on a common axis in such a manner that the acting portion of each cam overlaps the one above just $\frac{1}{8}$ of a circumference.

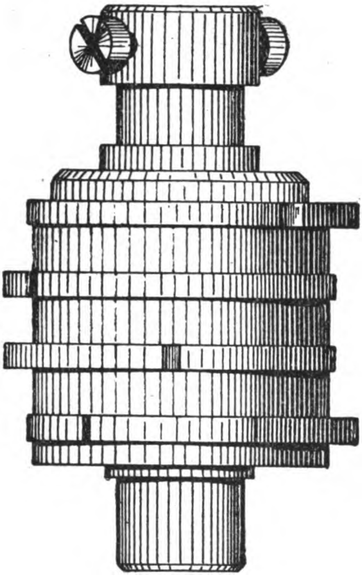


FIG. 8.—Cam collars.

44. The contact plate is provided with proper bearings for the cam collars, and carries the four cam levers with the cam wheels *a, a, a, a*, Fig. 9, also the four insulated contact springs N, E, S, W, the points of which approach closely the corresponding cam lever, but make contact only when the lever is pressed outward by one of the cams, thus closing an electric circuit through that particular spring. It will be remembered that adjacent cams overlap for a portion of their extent; this, in certain positions of the cams, brings two of the springs N, E, S, W into contact—thus, N and E, for example, which indicates the direction *northeast*. By these devices, with four springs and circuits a record of eight possible directions may be secured.

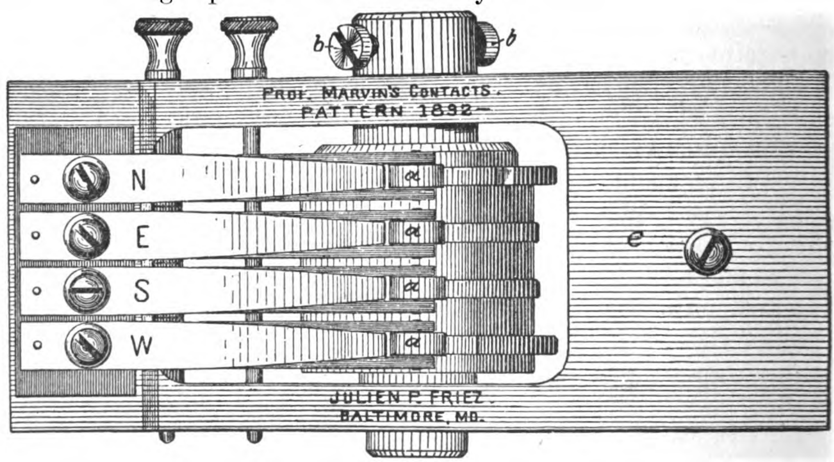


FIG. 9.—Electrical contacts.

45. When the contact mechanisms are placed in the contact box the inside rod passes centrally through the cam collars, which are

securely clamped thereto by the set-screws *b*, *b*. The contact plate is not rigidly fixed in the contact box, but is simply prevented from turning by means of two screws passing through opposite sides of the box, and with their points entering loosely into appropriate slots in the ends of the contact plate. The whole mechanism simply hangs on the slender inside rod of the vane, and offers only the slightest resistance to rotation in the bearings of the cam collars and the cam levers.

The standard vane constructed as described above, and provided with contacts for electrical registration, will turn with very light winds.

46. *How to erect a standard wind vane.*—The position selected for the exposure of the vane should be as unobstructed as possible by chimneys, domes, ventilators, towers, or adjacent buildings, or other objects that may interfere with the free movement of the wind. In general the higher the support the better, but difficulties of construction, etc., limit the height to from 15 to 18 feet, and in some cases 24 feet.

The pieces of pipe forming the support are to be screwed together as tightly as possible, and with the cast-iron contact box (when this is to be used) at from 4 to 5 feet from the base.

47. The inside rod forming the axis of the vane should not be extended downward below the top section unless electrical contacts or a ceiling dial are to be used, and when either is used the extension should be made of ⅛-inch gas pipe. In joining this pipe together or to the rod, *a*, great care must be taken that the couplings are very tight and the sections as nearly as possible in line. No guides to this rod should be used, except in the case of ceiling dials, and then the entire stretch of rod from the guide, at *b*, to the ceiling should be as straight as possible and unobstructed by any narrow passages.

48. The inside rod should be placed in the support before the latter is erected, though it is possible to insert the rod afterwards, if necessary. In securing the guy rods to the roof or platform, special attention must be given to insure a firm hold not only of the iron shoe but of the flooring or roofing itself, as, if the latter is fastened only by nails, as is generally the case, it is a very easy matter to loosen these right up when screwing up the turn-buckles of the guy rods, and to draw the flooring or roofing up from the rafters.

49. *To straighten inside rod.*—When the electrical contacts and inside rod are used, the latter must be straightened by the following method:

Before placing the vane on the support and the contact plate in the box an assistant should climb to the top of the support by a ladder or the iron steps on the pipe and twirl the axis of the vane about between the thumb and fingers, while the turning of the inside rod is watched within the contact box. If the inside rod is not in proper alignment the portion passing through the contact box will describe a circular movement rather than revolve on a line through its center. To remedy this the rod must be lifted up so as to bring the joint, marked *c*, above the top of the support, and be bent gently at that point until, by the twirling test, it is found the portion passing through the contact box does not describe a noticeable circle; that is, the revolution is nearly or quite about a line through the center of the pipe itself. By this method a very accurate alignment of the rod can be made.

50. *Oiling vane.*—The bearings of the vane are so designed that it makes very little difference whether they are oiled or not. In mounting a vane, however, a little oil should be put upon the iron axis along the portions passing through the guide just below the anti-friction rollers and at *b*; also, a *very little* upon the *axes* of the anti-friction rollers. *Oil must not be applied to the surfaces upon which the anti-friction wheels roll or upon the wheels themselves*, as this causes dust to adhere and accumulate and finally block up the free rolling of the wheels.

Two oil holes are provided in the bearings of the cam collars and these should be lubricated from the start, and from time to time afterwards as may appear necessary.

51. The inside rod having been straightened and oiled, as described above, the electrical contact plate is placed in the box and the inside rod lowered and passed through the hole in the cam collars. The points of the screws passing through opposite sides of the contact box are then caught into the slots in the ends of the contact plate. The vane itself is next placed upon the top of the rod. The cam collar is fastened to the inside rod at the time the vane is adjusted to the true meridian.

52. *To adjust vanes to true meridian.*—When vanes are provided with electrical contacts, or with the four direction arms shown at *N*, *S*, the cam collars must be so clamped to the inside rod, or the cross-arms to the top of the support that, for example, when the vane itself points truly north the center of the particular cam giving a north direction record will be exactly opposite the center of the wheel of the corresponding contact lever; and that the north and south direction arms at the top coincide with the vane. To secure this adjustment it is necessary to hold the vane accurately in a north and south position or such other principal direction as may be convenient, and adjust the cam collars on the inside rod so that the central line (engraved on each cam collar) on the particular collar corresponding to the direction of the vane will be exactly opposite the center of the wheel of the corresponding contact lever. When in this position the contact plate should be free from both the bottom and top of the contact box and

be held by the two screws passing through opposite sides of the contact box and entering into the grooves or slots made in the edges of the contact plate. Special pains should be taken to fasten the set-screws on the cam collars firmly to the inside rod. This should be done by alternately tightening and loosening the screw a little so as to cause its sharp point to enter, more or less, into the metal of the inside rod. Both clamping screws on the cam collars should be firmly tightened. After the screws are tightened careful comparison should be made to insure that the cam collars are fixed so that the center of the particular cam comes opposite, *exactly*, the contact lever when the vane is held fixed in its true direction.

The great difficulty of making the adjustment above is in holding the vane in any particular direction, according to the true meridian. Also in ascertaining the true meridian, since iron roofs and the iron of the vane support itself may quite prevent the use of a magnetic compass.

53. The following suggestions may be used to great advantage in the absence of a nephoscope or similar instrument:

(*a*) Provide an ordinary mirror a foot or so long and rule across this with a pen some sort of a straight line on the surface of the glass, which line is extended across the frame. Drive a pin perpendicularly on this line at opposite sides of the mirror.

(*b*) Select also, if possible, some distant object more or less sharply defined, such as a building, smokestack, or other object, and which (from a map, or by compass, or such other means as may be possible) has been found to be, let us say, due north from the station.

(*c*) Place the mirror in the vicinity of the wind-vane support, with its surface accurately horizontal, and so that the vane can be conveniently seen reflected therein.

(*d*) Adjust the mirror, by sighting, so that the two pins are ranged exactly in line with the distant object above referred to. With the mirror in this position cause the vane to be held so that its central line, by reflection, appears exactly parallel with or coincident to the line drawn on the mirror. The vane is now truly north and south, and the cam collars can be accurately adjusted.

II.—AUTOMATIC REGISTRATION OF WIND VELOCITY AND DIRECTION.

REGISTERS.

54. *Definition.*—The term *register* is used by the Weather Bureau to designate certain pieces of apparatus of which there are several distinct types, each apparatus acting in connection with some regular instrument to produce, usually by electrical means, a continuous and automatic record from the instrument. Thus, there is (1) the ane-

mometer register, formerly inaptly designated self-register, and called also Gibbon's self-register, single register, etc.; (2) the double register; (3) triple register; (4) tele-thermograph register, etc. In each case the register serves to produce, at a more or less distant point, a record of the passing condition of the instrument to which it is attached.

55. *Single register.*—The "single" anemometer register for recording the velocity of the wind is shown in Fig. 10. A clock gives regu-

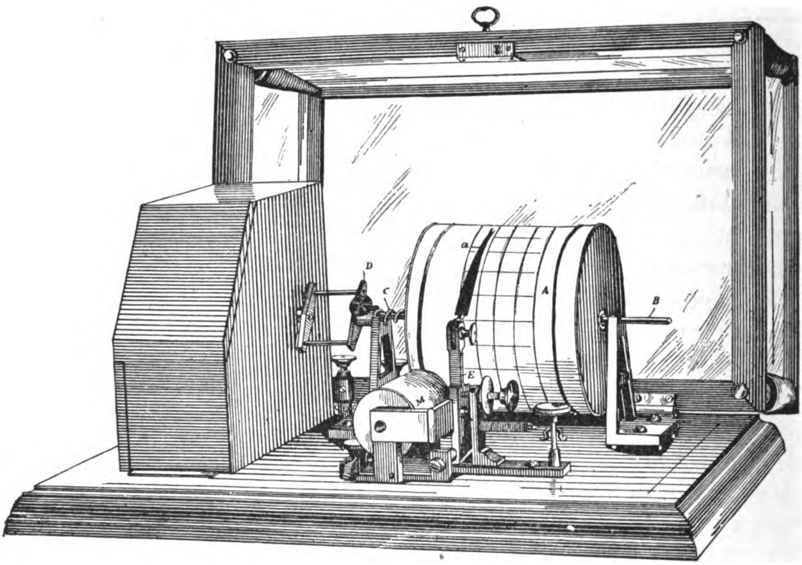


FIG. 10.—Single register.

lar and uniform motion to a cylinder, A, at the rate of one revolution in six hours; the cylinder at the same time moving endwise by the steep screw C, on its axis, B. The surface of the cylinder is covered with a ruled sheet of paper adapted to receive the record, which is traced by means of a pen or pencil, a, attached to the armature, E, of the electro-magnet, M. The standard Weather Bureau pen is shown separately in Fig. 11. The pen traces a spiral line on the sheet of paper, but by the action of the electro-magnet short lateral strokes or offsets are made to one side of the line whenever an electrical current is passed through the coils of the magnet. As soon as the current is broken the armature and pen are drawn back to the main line by a spring.

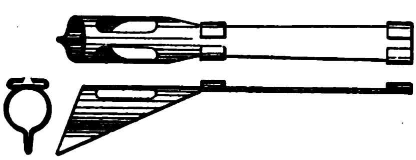


FIG. 11.—Register pen.

56. To use this register for recording the wind velocity, the anemometer, properly exposed as described in paragraph 35, is joined with the register and a battery by means of insulated copper wires.

57. Under these circumstances the armature and pen on the register will be alternately drawn aside and released every time one of the dial pins on the anemometer passes the contact spring and closes the electric circuit, as explained in paragraph 6.

58. Only the best insulated copper wire should be used for connecting up the anemometer. That regularly used by this Bureau is No. 18 American Wire Gauge, two-conductor cable, Okonite insulation, with braided covering.

59. The cable is securely tied to the support near the anemometer, and the two ends separated for a short distance so that each wire will easily reach a binding post on the anemometer. The remainder of the cable should be run and secured from point to point in such manner that it cannot be disturbed by the wind or other causes and will not be easily subject to abrasion by swaying motion, etc.

60. The battery most frequently used, and, in the long run affording the best results, is the ordinary "crow-foot gravity," 6-inch cells, working on open circuit. For a circuit in which the total length of wire does not exceed 150 to 200 feet, three or four cells of battery are generally sufficient for the single register.

61. *Weekly anemometer register.*—Another and improved form of single anemometer register is clearly shown in Fig. 12. The record

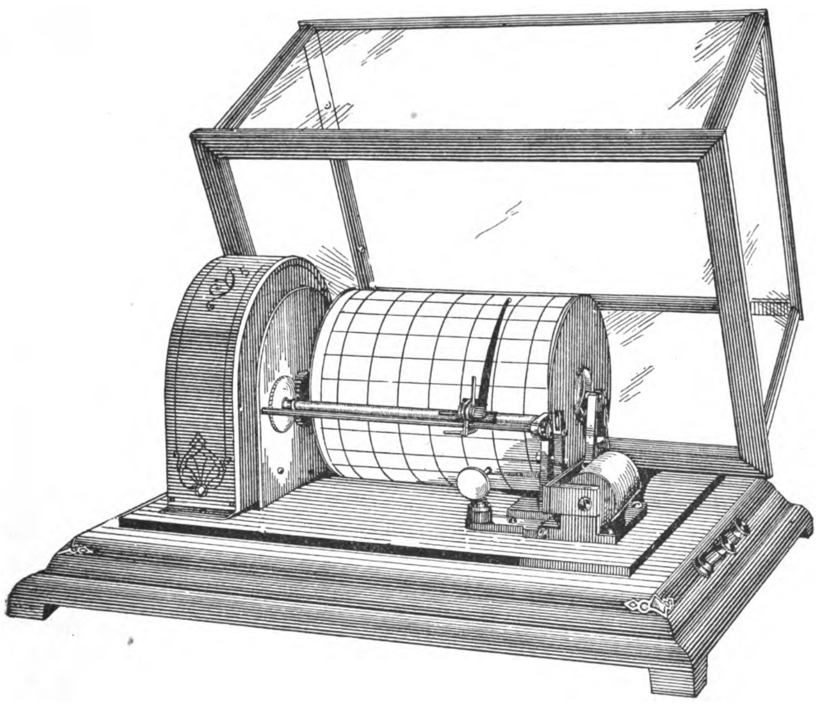


Fig. 12.—Weekly anemometer register.

obtained from this instrument is essentially the same as that from the *daily* register described in paragraph 55, except that the recording cylinder is made larger and the mechanism so arranged as to permit of an *entire* week's record being made on *one* sheet or form.

In this register the *pen* moves very slowly across the cylinder, the latter revolving, horizontally, on its axis, without any such end motion as in the ordinary "single register." The miles of wind velocity are indicated by short lateral strokes imparted to the screw (and pen and carriage attached thereto) by means of the armature of the electro-magnet at the right.

62. *Anemograph defined (double register).*—The apparatus described above for recording wind velocity, when complete with anemometer, is sometimes called an anemograph, but this latter word more properly applies to an apparatus which also records the direction of the wind. The instrument in this case is more commonly known in the Weather Bureau as a double register, and, as recently constructed, is exactly the same as the so-called triple register, except that the electro-magnet, *R*, Fig. 13, for recording rainfall, is omitted.

63. *Metrograph (triple register.)*—Instruments with which a continuous record of several meteorological phenomena are secured are often called meteorographs or metrographs. The triple register of the Weather Bureau is such an instrument, and upon it may be recorded the direction and velocity of the wind, rainfall, and by means of a newly invented sunshine recorder a continuous record of sunshine may now also be obtained. A general view of the instrument is shown in Fig. 13. The drum, *A*, upon which is placed the sheet of paper to receive the record, is made to revolve once in 6 hours by a clock movement, the cylinder shifting endwise, in the same manner as in the single registers. The electro-magnet, *V*, is called the wind-velocity magnet, and actuates the pen, *a*, in the manner described in paragraph 55, describing the "single register," so as to trace upon the sheet of paper a complete record of the velocity of the wind.

64. *Wind direction.*—The direction of the wind to eight points is recorded by means of the four magnets, seen at *W*, *W*. These are often called the direction magnets, and are connected electrically with contact springs, as described in paragraph 44, corresponding to the N., E., S., and W. points in wind direction. The armature of each magnet carries a long arm, the outer end of which has formed upon its under side either a small rounded point, or, sometimes, one of the letters N., E., S., W. This rests upon a small swinging ink-pad over the top of the cylinder. Whenever a current passes through a magnet the armature is drawn and forces the point or letter upon the end of the arm down upon the cylinder, the ink-pad being pushed aside at the same time. The imprint upon the paper of either the dot or letter indicates always a certain wind direction, depending upon its position. There being four magnets four directions may be thus

recorded, but as described in paragraph 44, the electrical contact mechanisms of the wind vane are so constructed that when the direction is intermediate between two principal points then *two* circuits will be closed; thus, for a northeast direction both the north and the east magnets will make a record upon the paper. In this way four magnets furnish eight possible directions.

The use of letters on the armatures of the direction magnets is found to give less satisfactory results than simple rounded points, and only a few instruments of this character are in use.

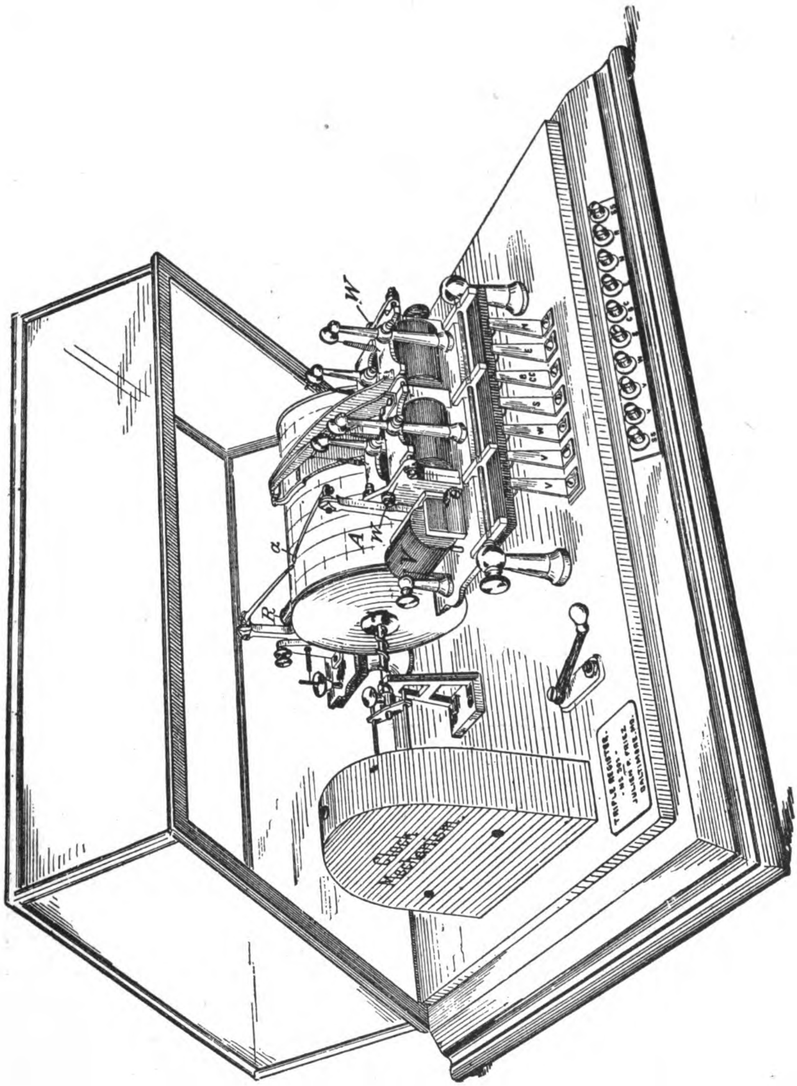


FIG. 13.—Improved triple register.

65. *Rainfall; sunshine.*—As the record of rainfall is blank for a great proportion of the time, and as it rains but little during sun-

shine, the magnet and the pen from the back generally used to record rainfall may, without serious interference, be used to also record sunshine by the electrical recorder which, with improved rain gauges, will be described in a subsequent circular. As explained there the electric circuit passes through the clock and during sunshine the current flows momentarily once each minute or five minutes. This makes a short lateral stroke in the line traced by the pen, and of itself is not distinguishable from one of the marks that might have been made by the rain gauge. A very little attention, however, on the part of observers and the proper marking of records with marginal notes will prevent any confusion of rain and sunshine records which, in fact, is much less liable to occur than would at first sight seem. The strokes of sunshine record occur with perfect regularity at uniform intervals and in a fixed relation to the 5-minute lines ruled on the sheet. The rainfall, however, is always very irregular and easily distinguishable.

66. *Description of clock contact.*—The several forms of instrument heretofore made are provided with slightly different kinds of contact mechanisms, each form representing some improvement over those previously used. In the majority of registers the contact is made by the rotation of a wheel having 12 pins or projections which, in turn, deflect a spring and momentarily close the electric circuit. The object sought in the construction of these contacts is (1) that the closure of the circuit shall be of very short duration, that is, of about one second, and (2) when the sunshine recorder is used with the triple registers it is desired that, with as few additional parts as possible, the clock contact shall close both the sunshine and the wind-direction circuits at, or about, the same time. One form of contact by which it was sought to secure the above objects is figured and described below.

The construction of the mechanism in this case is shown in Fig. 14. The wheel, *a*, having 12 teeth, is mounted upon a projecting arbor of the clock movement and revolves once each hour, that is, a tooth will pass any fixed point every five minutes. The wheel is not firmly attached to the clock arbor, but is free to revolve, which movement, however, is restricted within very narrow limits by means of the pin, *p*, passing through a hole in the wheel, *a*, larger than the pin. Finally, a feeble spring coiled about the axis of the wheel keeps the

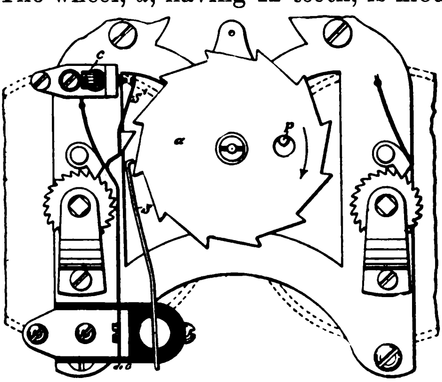


FIG. 14.—Five minute wind and sunshine clock contact.

latter in a position to be pressing against the pin, p, in the same direction as that in which the wheel is revolved by the clock. At s a comparatively stiff spring has its point projecting out into the path of the points of the wheel, a. As the latter revolves a tooth presently encounters the spring and the wheel, a, is held stationary for a short time during which the pin, p, passes across the hole in the wheel and by pressing against the opposite side urges the wheel forward against the pressure of the spring, s. By this action the point of the tooth is presently disengaged from the spring, s, whereupon the coiled spring causes the wheel, a, to make a sudden movement forward, upon which the feeble contact spring, s', is deflected so as to close an electrical circuit at the contact point, c, and also another circuit which passes through the spring, s', and the toothed wheel itself.

In an older form of this contact the wheel, a, revolves continuously with the clock, the stiff spring, s, is dispensed with, and as the points of the toothed wheel, a, pass the projection on the spring, s', the platinum tipped point of the latter closes the wind direction circuit through the contact screw, c.

67. Extended experience has shown that the 5-minute clock contact can not be made to close the circuits for the short period of time desired and still preserve a simple construction of the mechanism. The whole problem is much simplified by closing the circuits once each minute, and this form of contact proves very satisfactory. Perhaps the greatest objection to it is the increased danger of stopping the clock. The construction for closing two circuits is shown in Fig. 15. A small platinum-tipped hand, a, is fixed upon the second hand pinion of the clock, and its point rubs against the platinum-tipped contact springs, s, s', closing the circuit first through one and then through the other. The hand itself is made a part of the electric circuit in the manner more fully seen in the diagram of electric circuits, described in paragraph 70.

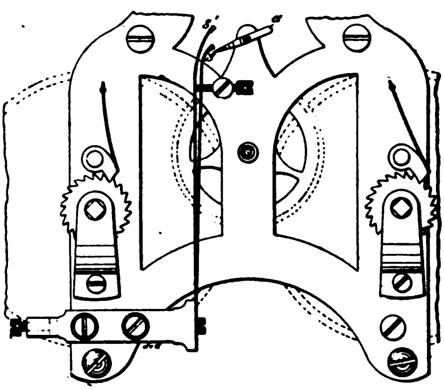


FIG. 15.—One minute wind and sunshine clock contact.

68. *Suggestions about running wires and cables for registers.*—When several registering instruments requiring a number of electric circuits are in use, or to be connected up, it is always best to use a cable containing a sufficient number of conductors, each insulated from the other, and much time is saved in the end if the several wires be each plainly marked or tagged at each end, so that any particular

wire may be utilized at any time. This is sometimes done by the use of different colored threads in the insulation, but such marking is often obscure and of little value. The wires of a cable not already marked should be identified before placing the cable in position. The two ends are picked out of the coil and the outer wrapping laid back 8 or 10 inches, at the same time stripping the insulation from the ends of the wires themselves. A battery, or some other source of electricity, and a galvanometer or telegraphic sounder, must then be brought into requisition. A telephone call-bell answers admirably. A battery, however, is really the only thing required. One of the wires of the cable is joined to one pole and the other end of the cable and a wire from the other pole of the battery brought up in a position convenient to be touched to the tongue, which is very sensitive to electric currents. The single wire from the battery is held against the tongue, while one after the other of those in the cable are touched in turn until the one is found through which the current flows. This one is at once marked, say "1," either by a small but substantial tag, or, if the insulation is of rubber or similar material, by cutting out a single V-shaped gash near the end. When No. 2 is identified this may be marked by two gashes, etc.

69. In case the cable is already in position the services of an assistant will be needed to shift connections and to mark the wires identified. One, at least, of the wires of almost every cable is marked by the manufacturer by some peculiarity of insulation. This wire should be permanently joined at one end with the battery, and at the other end of the cable first with one, then with each of the other wires of the cable in turn, until by testing in each case for currents each of the wires is identified and plainly marked. No difficulty from wrong connections will ever occur if this work is carefully and properly done. Failures in getting new instruments in operation are far more often due to insufficient care and attention in making all the connections correct throughout than to any other cause.

70. *Explanation of circuits.*—The diagram, Fig. 16, shows the electrical circuits for the latest pattern triple register, including sunshine circuit, but represents, in principle, the manner in which circuits of corresponding parts of the single and double registers are made.

(*a*) *Wind direction.*—The circuit for wind direction, starting from the battery, leads directly to a switch or control key on the register, thence through the clock mechanisms, and has joined to it one wire from each of the four direction magnets, N, E, S, and W. The remaining end of the wire of each of these magnets passes separately to corresponding binding posts, suitably marked, which are connected individually by wires with four corresponding insulated contact points located in the contact box of the wind vane. A single

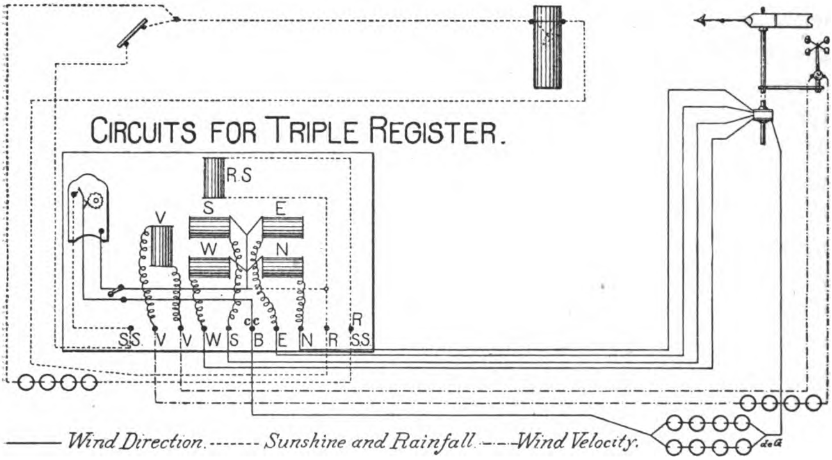


FIG. 16.

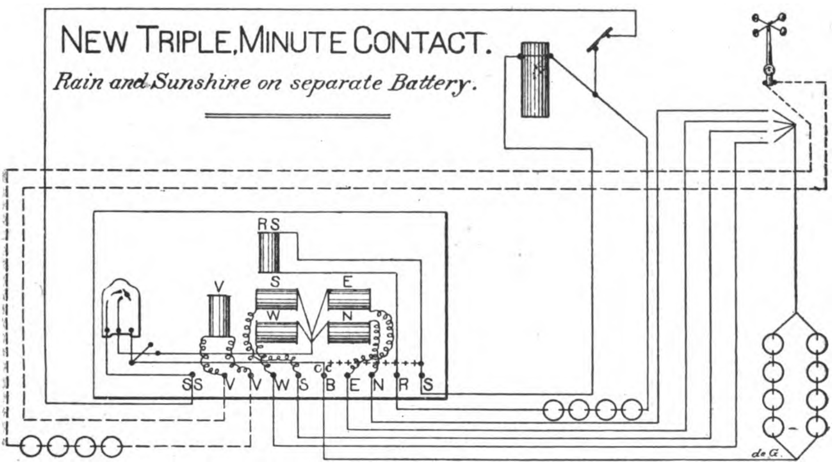


FIG. 17.

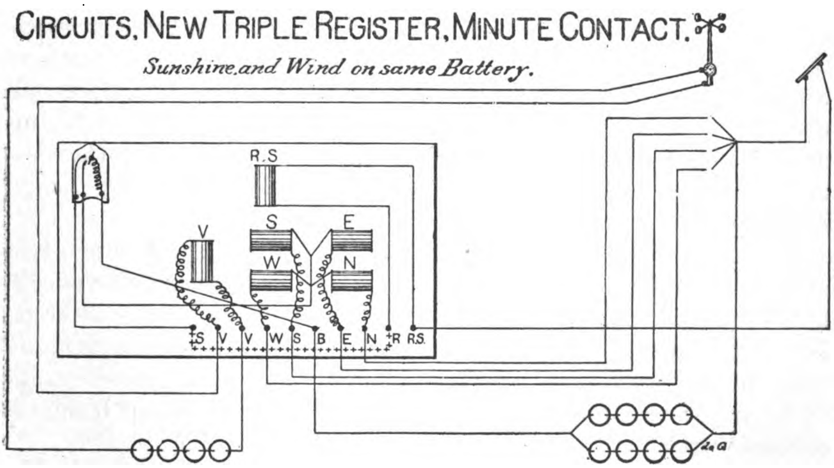


FIG. 18.

wire, generally called the "return wire," leads from a binding post on the metal contact plate to the remaining pole of the battery, and thus completes the wind-direction circuit. Either one or two of the contact points in the box are always closed, as explained in paragraph 44, and one or two circuits are, therefore, completed through the corresponding magnets of the register at each closure of the circuit in the clock, which, as explained, takes place every minute or every five minutes, as the case may be, thus producing the record described in paragraph 64. The small switch or key in the direction circuits is used only in testing the line, and simply enables one to close the circuit at any time without the delay of waiting for the closure in the clock.

(*b*) *Wind velocity.*—This circuit is very simple and direct. A wire leads from the battery to the magnet, thence to the anemometer, and returns directly to the battery.

(*c*) *Rain gauge.*—In case the rain gauge alone is used the circuit is made up in exactly the same manner as the one just described for the wind velocity, but is not shown in the diagram.

(*d*) *Rain and sunshine.*—In this case the same battery serves on both circuits and only three wires are required. Starting from the battery a wire connects directly to one end of the magnet coil at $s,\overset{R}{s}$. The other end of the coil divides into two circuits, one passing to a binding post, *R*, thence direct to the rain gauge; the other circuit passes first through the clock contact, thence to the binding post, *S*, *S*, and finally to the sunshine recorder. This circuit and the one from the rain gauge unite again after leaving their respective instruments, and pass thence direct to the battery.

On registers fitted with one-minute contacts the binding posts, *B*, *S*, are joined with a short piece of wire, marked + + + + on the diagram, Fig. 17, in case the rain and sunshine are recorded by use of a separate battery.

(*e*) *Sunshine on wind-direction battery.*—This arrangement lessens the battery required and presents no difficulties with the minute contact, since the sunshine circuit and the wind direction circuit are never closed at the same time. These circuits will be perfectly understood from the diagram, Fig. 18. The two posts *S*, *R*, on the register are joined by a short piece of wire. This is indicated by the line + + + + +.

71. *Lost motion and adjustment of record sheets.*—The record cylinders of the registers, described in the preceding pages, revolve once in 6 hours, so that the sheet makes just four revolutions in 24 hours. In order that the rulings on the sheet should correspond to actual times in every case, it is important that the length of the sheet exactly fit around the cylinder. If the latter is a little too small it may be enlarged with a thickness or so of paper.

72. It is of great importance that the record sheets of registers be adjusted so that their readings indicate correct time. Large errors are sometimes unnecessarily made in consequence of unavoidable looseness in the clockwork giving motion to the cylinder. The lost motion should always be "taken up" when the cylinder is set. This is accomplished by drawing the finger-tip lightly across the edge of the cylinder *in a direction opposite that in which the cylinder revolves.* The friction brings the cylinder very nearly to the normal condition in respect to time that it will have when running undisturbed. When so adjusted the recording pen should indicate exactly the correct time at that moment.

73. In all instruments of recent design the recording cylinders are mounted adjustably on their axes, so that without loosening screws or clamps of any kind the cylinder can be turned upon its axis under gentle friction and easily and accurately set at any moment desired, in much the same manner as the setting of the hands of a clock.

BATTERIES.

74. *Batteries.*—The electrical current serves such an important part in nearly all forms of registering instruments that the battery best adapted to the conditions becomes an important consideration. We can hardly hope to wholly escape the failure at some time of some of the registering instruments, and, although every instrument is made to work on "open circuit," it often happens that when failure does occur one circuit or another will be found closed, in which case any one of the numerous so-called "open circuit" batteries will suffer very seriously, or, as is most likely, will be completely run down. Moreover, as occurs with anemometers provided with the 10-mile contact (see paragraph 6), the circuit is sometimes in calms closed for over an hour, so that only those batteries can be used that are proof against short circuiting.

75. A great number and variety of batteries have been tried at this office, but none have shown any sensible advantage over the common "crow-foot" gravity battery, and many are quite inferior.

76. The gravity or Callaud battery is so well known and in such general use as not to need a description. Aside from its extreme simplicity its special advantage lies in the general constancy of current, and the circumstance that prolonged closure of circuits, either by accident or otherwise, effects an improvement in the battery, rather than otherwise. When in the best condition it presents a very beautiful appearance. The liquid in the upper portion of the cell is clear and colorless, and a deep transparent blue at the bottom, the surfaces of the copper being covered with a sparkling crystal-like deposit of pure metallic copper. This condition does not occur, however, unless the current flows frequently, at least nearly half the time, and if such

is not the case, the blue coloring of the solution will extend quite to the top, losing in transparency, and if the circuit is closed only on rare occasions, it will be found that the battery will lose strength and the solutions will show a marked tendency to dissolve up the upper edges of the copper, sometimes eating off completely the wire joined to the plate. A copperish deposit may also tend to form on the zinc.

These objectionable results in the battery are less likely to occur if the quantity of sulphate of copper be kept small; whereas the sulphate may be from 1 to 2 inches deep in a battery operating a circuit that is closed a large part of the time.

77. *Suggestions about maintaining batteries.*—When a battery is freshly set up very little current can be obtained from it, owing to the fact that the chemicals are only partly in solution and that the liquid in that condition presents an unusual resistance.

78. The action of a new battery is hastened and improved by making up the solutions with warm water, or by the addition of either sulphate of zinc or a little sulphuric acid to the cells. One of the best methods is to employ the strong solution from old batteries, if this is available. If not in full working condition, and when not needed for immediate use, each cell should be short-circuited by joining the wire from the copper directly into the zinc. In this case the solution after a few hours will become clear, the blue color will prevail only at the bottom, and the copper will soon become very bright and sparkling.

79. The blue sulphate of copper solution at the bottom of the cell is decomposed into metallic copper, which is deposited upon the copper plate, and sulphuric acid, which remains in solution and diffuses its way more or less to the top of the battery, where action upon the zinc follows, producing sulphate of zinc, which also remains in solution, but from its less density this solution tends to float upon the more dense sulphate of copper solution at the bottom.

80. After continued action of the battery for a longer or shorter time the solutions become more and more dense, and the zinc becomes coated with a soft mud-like coating which should be removed and the solution diluted with fresh water from time to time. A small battery hydrometer, showing strength of the solutions by the depth at which it floats, together with a battery syringe, are very convenient and useful in maintaining batteries in a uniformly good condition.

81. If the sulphate of zinc solution is allowed to become too strong it will climb up around the top edges of the jars, zincs, etc., and leave white incrustations of the partially dry salt that are very objectionable and unsightly, not to mention injurious to insulation and the possible leakage and waste of currents. This action of the sulphate of zinc is lessened by painting the tops of the battery jars with asphaltum varnish.

82. Batteries should be attended to regularly once each week, the zincs cleaned, and cells wiped off clean and free from incrustations. In cleaning zincs it is a great advantage to have an extra set which can be quickly exchanged for those in use, and avoid a serious interruption in the circuits. The old set can then be cleaned at leisure and held in readiness for use the next time.

83. *Arrangement of cells.*—For a single circuit, such as that of the anemometer, three or four cells are sufficient unless the line is very long, and these should be joined "in series," that is, the copper of one cell joins to the zinc of the next, etc.

84. In the case of wind direction it will be seen that when two contact springs are closed the current from the battery divides in passing through the two coils, so that each coil gets only half as much current as if only one contact spring was closed. Strictly speaking, the divided current is a little greater than half the current for a single circuit, because the line resistance is less with two coils "in parallel" than with one, and the current from the battery will be correspondingly stronger. The advantage on this account will be greater if the resistance of the battery is smaller. The wind-direction battery is, therefore, generally made up with 6 or 8 cells arranged in two sets of three or four each. In each set the copper of one cell joins the zinc of the next, but the two sets are joined together into one battery by placing the two terminal coppers to one line wire and the terminal zincs to the other line wire. This arrangement of batteries is often styled "in parallel," or "for quantity," and is clearly indicated in the diagram of circuits, Figs. 16, 17, and 18.

It is more advantageous to have one battery at work on several different circuits than to have several independent batteries, since the gravity cell keeps in better condition the more it is used.

APPENDIX.

U. S. Department of Agriculture,
Weather Bureau, *Washington, D. C., February* 15, 1893.

The following instructions, with the descriptive matter preceding, will replace pages 39 to 55, "General Instructions to Observers," 1887.

Mark W. Harrington,
Chief of Weather Bureau.

INSTRUCTIONS, ANEMOMETRY.

I.—ANEMOMETER.

85. *Exposure.*—The exposure of anemometers will be selected with a view to satisfying, as far as possible, the general principles discussed in paragraph 35.

86. *Anemometers oiled.*—An anemometer will never be exposed without first thoroughly oiling the top bearing and filling the cup-like bearing at the bottom of the spindle. The remaining parts will be oiled if necessary.

87. Before a new anemometer is exposed the observer will assure himself, by such tests and suggestions as described in paragraphs 22, 23, and 24, that the instrument is in good condition.

88. *Oiled each Saturday.*—When in use the anemometer will be oiled each Saturday and the fact noted in the Daily Journal. Only the clock oil furnished from this office will be used, and the observer will be guided by the provisions of paragraphs 26 and 27.

89. *Anemometers exchanged.*—As far as possible each station furnished anemometers will be supplied with two. Observers will keep careful watch of the one exposed that it is always freely lubricated and in good condition.

90. It is desired that the extra anemometer be not used except when necessary; but it will be exchanged with the station instrument once each month for a period not to exceed 24 hours, during which the station instrument must be cleaned and put in thoroughly good order, according to the provisions of paragraphs 32 and 33. The dial readings of both anemometers, with their official numbers, together with marginal notes stating the circumstances, will be entered on the anemometer sheet, in accordance with instructions on the form. When exchange of instruments is made the dial of one anemometer will not be set to read the same as the one exposed.

91. Thorough cleaning once a month is not necessary, in general, if the anemometer is properly oiled each week, but this statement will not, in any case, serve as excuse in the event of injury to an anemometer

from neglect, either of weekly oiling or monthly cleaning, and observers are informed that the most extended experience and severe tests made at this office demonstrate the *impossibility*, if these instructions are conscientiously observed, of anemometer bearings becoming scratched, worn, and abraded, and spindles becoming fast in the bearings.

92. This office, therefore, finds but one explanation for injuries of this kind, namely, *neglect*, and, as the consequence of such neglect is always loss of valuable record, in some cases insidious and extending over a long time, it is of a very serious nature, and cases of its occurrence will be treated accordingly.

93. *Defective anemometers.*—When, upon examination, the bearings of an anemometer are found to be in a bad condition, as described in paragraphs 29 and 30, or the instrument is otherwise defective and can not be repaired by the observer, request should be made for another instrument, and *special care will be taken to prevent altering or modifying in any way whatsoever the condition of the defective parts of the anemometer*, which, as a whole, will be called in to this office, and, in general, particular parts of instruments will never be supplied, but the anemometer, without cups, will be replaced.

94. *Requisition for anemometers.*—Whenever requisition is made for a new anemometer, to replace an unserviceable or defective instrument, the letter must give all particulars possible as to *how* the anemometer became unserviceable; the nature of the defects observed; how long the instrument has been in constant operation; and also the *official* number of the instrument.

95. *Current velocity, how obtained from register.*—To obtain the current velocity from the anemometer record, take the number of spaces and parts of spaces between the mile marks recorded in the five minutes preceding the moment considered and multiply the result by twelve, *except* when the wind has blown *less* than twelve miles an hour, when the velocity for that hour will be determined as shown by the second example below.

First example. Suppose the number of spaces indicating mile marks between 7.55 p. m. and 8 p. m. was $1\frac{1}{4}$, then the velocity of the wind to be recorded at 8 p. m. is $1\frac{1}{4} \times 12 = 15$ miles per hour.

Second example. If the interval between the last two mile marks is 7 minutes, then the current hourly velocity would be obtained by dividing 60 by $7 = 8\frac{4}{7}$ miles, recorded as 9 miles.

When the anemometer cups are not moving at the time of observation, the wind will be recorded as calm, whether or not one or more miles have been recorded during the last hour; if the cups are moving, a velocity of one mile or more will be recorded.

96. *Maximum velocity, how obtained from register.*—The maximum velocity of wind for any period will be obtained by considering the number of spaces and fractions thereof between the mile marks in any five

minutes where the velocity is the greatest and multiplying the result by twelve, the product will be the maximum velocity for that period.

If the shortest space between two mile marks in the period covers more than five minutes of time, then the time expiring in said space will be the basis of the calculation. Example: If the shortest space between two mile marks is thirteen minutes, then 60÷13=4.6 miles per hour for the maximum velocity, which will be recorded as 5 miles.

97. The *extreme velocity each day* (from midnight to midnight) will be ascertained with reference to *the mile* of wind recorded in the shortest time, thus: find the two marks *nearest each other* on the anemometer sheet, calculate accurately the amount of time *between* these two marks (from beginning to beginning or from ending to ending), divide 60 by this amount, and the quotient will be the *extreme velocity.* Example: The space of time between two marks nearest each other is two minutes: 60÷2=30, therefore 30 miles is the extreme velocity for the day. Accidental movements of the cylinder sometimes introduce false records of extreme velocities that have not occurred. The appearance of the record immediately adjacent generally indicates the existence of this defect and, if noticed, the reports of extreme velocity will be explained by marginal note.

98. *Current wind velocity; how obtained from dial.*—To obtain the current velocity of the wind from the anemometer make two readings of the outer dial with an interval of five minutes between them. The *difference* between these readings will be the distance, in miles and tenths, traveled by the wind in that interval. This, multiplied by 12, will give the indicated velocity in miles per hour. Example: Suppose the index of the anemometer to be at 3.4 on the outer dial when the first reading is taken and at 4.1 five minutes after, the difference, 0.7 mile, is the distance traveled in that time; and this, multiplied by 12, gives a velocity of 8.4 miles per hour. Whole numbers only will be used in expressing the velocity; when the decimal is over five-tenths, the whole number will be increased by one; when less than five-tenths it will be dropped; when just five-tenths an odd unit's figure will be increased by one, but an even number will not be changed; for example, such numbers as 13.5 will be changed to 14, the "3" being odd, while 12.5 will remain simply 12, the "2" being even.

99. *The total movement by register* for any period will be obtained by counting the number of marks in the period.

100. *Wind movement from noon to noon by dial.*—To obtain the total movement of the wind from noon to noon, subtract the reading of the anemometer dial at 12 noon of the preceding day from the reading taken at 12 noon of the current day, the difference will be the total movement. When the reading of the anemometer is less than the reading of the preceding day, 990 miles will be added to it, and the remainder, after subtracting the reading of the preceding day,

will be the total movement. Example: The dial reading of to-day is 91, and that of yesterday was 950, hence we have 91+990=1081; 1081—950=131, the total movement of the wind in miles from noon to noon.

101. *Velocity of wind, estimated.*—Whenever, through failure or otherwise, instruments are not available for directly measuring the wind velocity it will be estimated by reference to the following scale:

Name.	Miles per hour.	Apparent effect.
Calm	0	No visible horizontal motion to inanimate matter.
Light	1 to 2	Causes smoke to move from the vertical.
Gentle	3 to 5	Moves leaves of trees.
Fresh	6 to 14	Moves small branches of trees and blows up dust.
Brisk	15 to 24	Good sailing breeze and makes white caps.
High	25 to 39	Sways trees and breaks small branches.
Gale	40 to 59	Dangerous for sailing vessels.
Storm	60 to 79	Prostrates exposed trees and frail houses.
Hurricane	80 or more.	Prostrates everything.

102. *Wind data for public, how furnished.*—Observers, when called upon by the public for wind data, will furnish, if *velocities* be desired, the ordinary observed velocities, and fully explain to the applicant the method of obtaining the *corrected* velocities, as explained in paragraphs 11 and 12, furnishing, if necessary, a copy of the table there given.

If *pressures* be desired, or both velocities and pressures, a similar course will be pursued, using the data in paragraphs 13 and 14, the observer exercising great care to see that the applicant is fully informed upon the subject.

II.—ANEMOSCOPE.

103. *Exposure and erection.*—The general principles stated in paragraph 46 will guide observers in selecting exposures for wind vanes, and, if placed near the anemometer support, the one must be not less than 1½ to 2 feet higher than the other.

104. Observers will be held responsible for the erection of the support and vane to the extent of supervising the mechanics employed to do the work, and will see (1) that the sections of pipe screw together firmly and straight; (2) that the inside rod is straight and moves freely in its bearings throughout each entire revolution. This will be tested by twirling the vane rod at the top, before the vane is attached, paragraph 49, unless some special cause prevents. (3) When possible the vane rod will be oiled where it passes through its bearings, Fig. 7, and the rod straightened by the method described in paragraph 49; (4) that the electrical contacts are properly adjusted so that, in the case of new style contacts, the plate is perfectly free from all sides of the contact box, and, with the old style, that the little rollers on the contact levers are accurately opposite the corresponding cams; (5) that when old style contacts are used, the thick

rod passing through the box and the cam collar is oiled at the portions passing through the box; (6) that the shoes for the guy rods are securely fastened and in such positions as to allow plenty of space in the turn-buckles for tightening. The guy rods must be disposed around the support at equal angular distances from each other.

105. *Adjustment to true meridian.*—The cam collar or direction cross-arms will be adjusted to the true meridian in accordance with the method given in paragraph 52 or 53, unless such a course is impossible for some special reason, in which case the adjustment will be made the best possible, and a report forwarded giving circumstances.

106. *Oiling contact mechanisms.*—The only parts of the electrical contacts needing oil are the *axes* of the small rollers on the contact levers, also the portions of the inside rod where it passes through the top and bottom of the contact box. Contact plates, of the newest construction, are provided with two oil holes, one at top and one at the bottom bearing of cam collars. These parts will be examined from time to time and oiled, as may be required.

107. *Vane examined.*—The vane and parts must be examined from time to time, and its behavior in light winds noticed to see that it moves with the usual freedom in its bearings.

A slender stick 1 to 2 feet long, with a light thread attached to one end, may be tacked to the side of the vane and project above it, the thread showing true wind directions. The new pattern vanes and old ones, if carefully set up, and without contacts, should shift with very light winds.

III.—REGISTERS.

108. *Cables and electrical conductors.*—The wires and cable connecting recording instruments, batteries, etc., will be run over the shortest practicable route, carefully placed, and well supported at all points so as to escape accidental or unnecessary injury or interruption of circuit by abrasion of insulation, breaking of wire, etc. Numerous joints are to be avoided, but when a joint is made the wires must be brightened and very firmly twisted together, or soldered if practicable, covering the wire afterwards with insulating tape, if available.

109. *Adjusting record cylinders to correct time.*—Special care must be observed to prevent erroneous records in respect to time, and the principles pointed out in paragraph 72 will be followed in setting records and every effort made to regulate clock carefully.

Additional instructions in regard to registers and records will be found in Circular A, Instrument Room.

IV.—BATTERIES.

110. Observers will give such frequent attention to batteries as will prevent loss of record and failure of instruments on that account.

R.W.